LEDs MAGAZINE

LEDs Magazine Review

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Issue 9 October 2006

Editor: *Tim Whitaker* tim.whitaker@ledsmagazine.com **Advertising sales:** joanna@ledsmagazine.com **Cabot Media Ltd** Tel: +44 (0)117 941 5378

NEWS & ANALYSIS
Cree unveils 160 lumen XLamp LED...New Philips Lumileds LED plant in Singapore will double capacity...Color Kinetics licenses to Robe, Osram Sylvania...DOE launches testing program for solid-state lighting...and more **p3**

INTERVIEW
GELcore positions itself to address the solid-state illumination market p8

STREETLIGHTING
On the verge: LEDs ready to challenge incumbent light sources in the streetlighting market p11

COLOR MIXING
Six-color mixing and warm-white/green/blue offer new approaches to generating white light p19

VEHICLES
Automotive lighting design with LEDs puts the 'super' into the Ford Super Chief concept vehicle p23

OPTICAL DESIGN
Integrated optimization capabilities provide a robust tool for LED backlight design p27

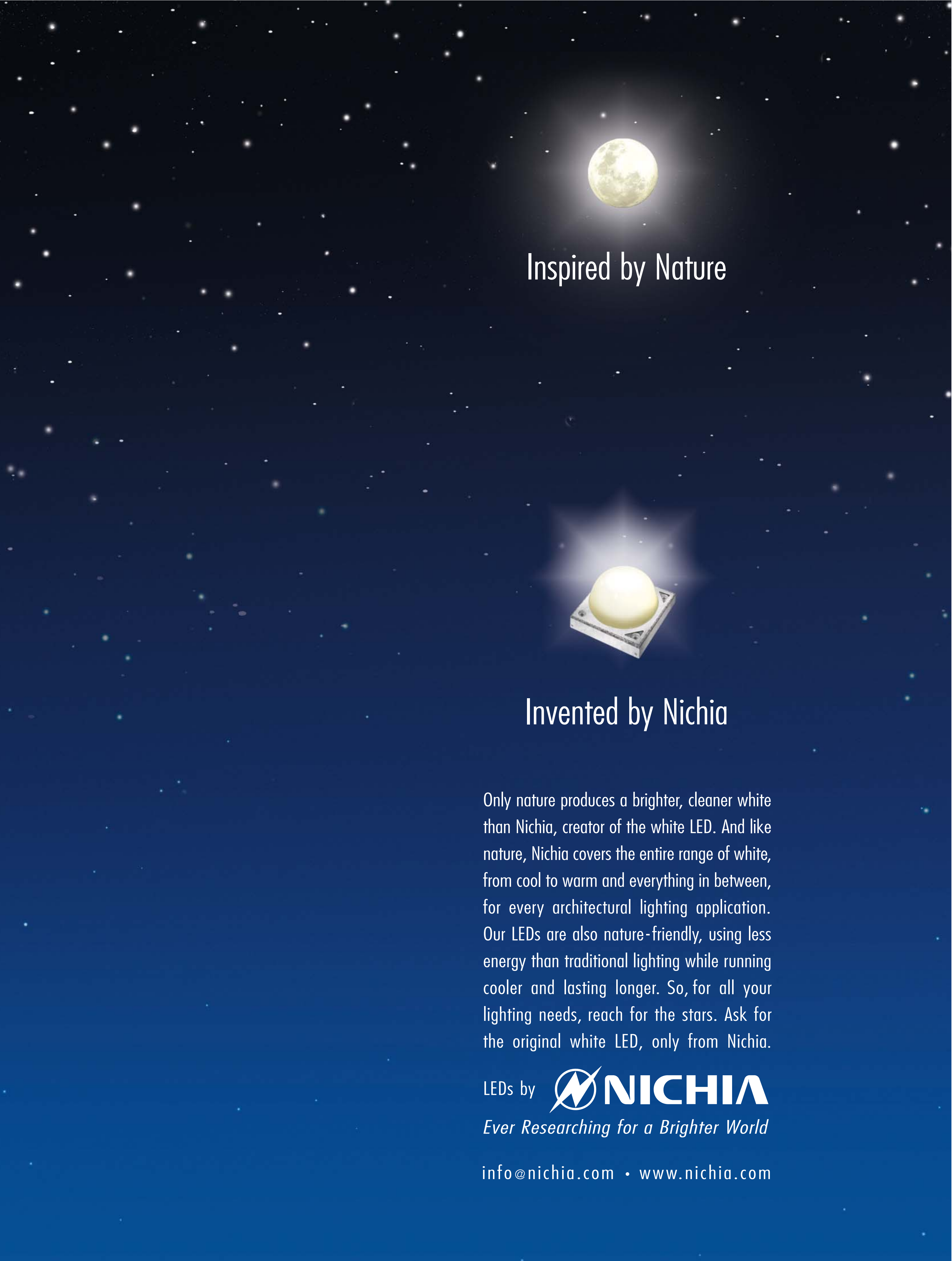
PHOTONICS CLUSTER
Solid-State Lighting and LED News from the Photonics Cluster (UK) p30

LED performance has reached the point at which LED street lighting is economically viable. **p11**

LEDs technologies developed for concept cars could soon transfer into production. **p23**

GELcore's David Elien reveals more about his company's partnership with Nichia. **p8**

LEDs Magazine is published by Cabot Media Ltd, Easton Business Centre, Felix Road, Bristol BS5 0HE, UK.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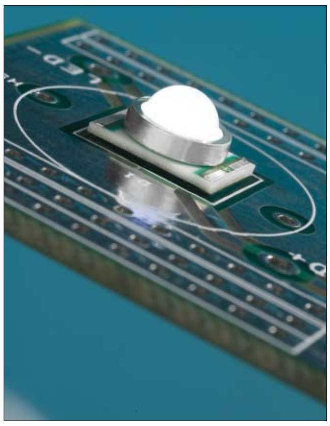
LIGHTING

Cree unveils high-output XLamp power LED

US LED manufacturer Cree has opened up a whole new field of general lighting applications with its latest generation of XLamp power LEDs. The company describes the XR-E series as a "new class of lighting LED". The headline figures show a luminous flux of up to 95 lm at 350 mA, equivalent to a luminous efficacy of 85 lm/W. At a current of 700 mA, the output is as high as 160 lm for the top bin.

These are highly impressive numbers, but the most useful comparison is given by the typical values at the center of the production distribution. For the XR-E, these numbers are 80 lm at 350 mA, with 70 lm/W. Many low-power LEDs operating at 20 mA would struggle to achieve this efficacy.



Mark McClear, Cree's director of marketing for solid-state lighting, emphasized that LEDs typically producing 80 lm are already in volume production. "We've already shipped more than 0.25 million devices," he told LEDs Magazine. In comparison, Cree's current-generation XLamp 7090 XR yields "only" 57 lm at 350 mA – equivalent to 47 lm/W. Osram's new Platinum Dragon device (see below) produces 70 lm at 700 mA, and has an efficacy of 30 lm/W.

Cree says that its new LEDs are designed to enable general lighting applications, such as streetlighting, retail high-bay lighting and parking-garage low-bay lighting, as well as to improve light quality in consumer applications, such as flashlights. In McClear's view, the leap in performance demonstrated by Cree will now make LEDs a cost-effective alternative to traditional lighting technologies in many general lighting applications.

The increased performance of the XR-E is due to several improvements in chip and phosphor technology, says McClear. The new LED retains the same package as its predecessor. It has a very low forward voltage, – around 3.3 V at 350 mA – contributing to lower power consumption and it also has vastly improved color uniformity. Cree has started to use a different phosphor process to deposit a thin, uniform layer of material directly onto the chip surface.

EZBright LED chip

The XR-E is the first power LED based on Cree's EZBright 1000 LED chip, which was unveiled last month (see www.ledsmagazine.com/articles/news/3/9/2). The blue 1 × 1 mm EZBright1000 chip, measured as a bare die, has a power output of up to 370 mW at 350 mA drive current, and 800 mW at 1 A drive current. This is twice the output of Cree's current XBright power chips.

Cree's XLamp product line, as an internal customer for Cree's chips, has already used the chips to make big performance improvements, and Cree expects its external customers to do the same, says Scott Schwab, Cree VP and general manager of optoelectronics.

The EZBright1000 is a square chip with an edge of 980 μm. It doesn't have bevelled edges like the XBright. Most significantly, in terms of light extraction, it is only 100 μm thick. Schwab says that Cree can not disclose the details of the design, but one difference these chips exhibit compared with Cree's other chips is the textured surface that helps to guide the light. "In addition, we have created a structure that has very low levels of optical losses, allowing us increased efficiency," he said.

LICENSING

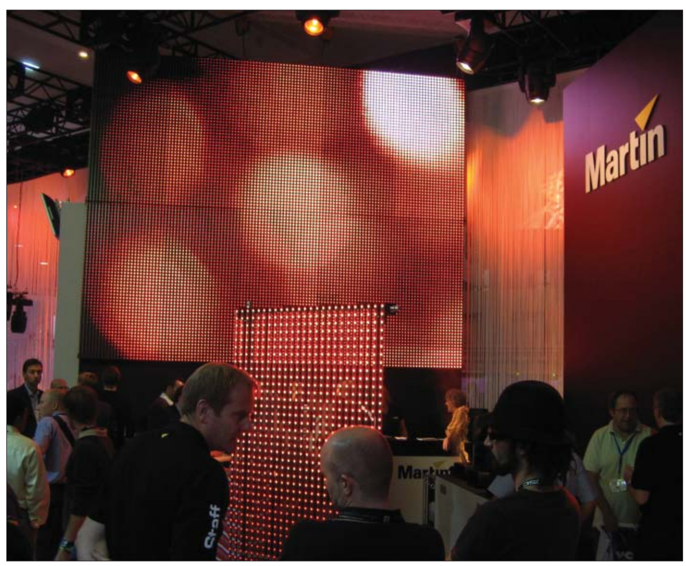
Color Kinetics licenses to Robe and Osram Sylvania

Color Kinetics has announced two more licensing agreements with significant partners. The Boston, MA-based company has licensed its considerable patent portfolio to Robe Show Lighting. Based in Hazivice, Czech Republic, Robe is a manufacturer of moving light systems that are widely used in theatrical, touring, television and other entertainment applications.

CK's other recent deal is with Osram Sylvania, the North American operation of lighting giant Osram GmbH. Osram Sylvania will license and use CK's technology and patents for a product to be marketed by Gotham Architectural Downlighting, an Acuity Brands company.

Specifically, Osram Sylvania will create an intelligent, multicolor LED system for Gotham, which develops downlighting products that enhance the appearance of modern spaces. Acuity Brands Lighting is one of the world's leading providers of lighting fixtures.

Bill Sims, CK's president and CEO, described the agreement as "significant" and said: "Earning the Osram Sylvania stamp of validation sends a strong message to the industry, and reaffirms the value of the innovations protected by our broad patent portfolio."



Martin Professional, a Denmark-based company that licensed CK's technology in May 2006, launched two LED products at this year's PLASA show (see www.ledsmagazine.com/articles/news/3/9/18). The LED light curtain is built from acrylic tubes containing RGB LED pixels with a spacing of 40 mm, which can be built into a display with a transparency of 60%. The other product was the Stagebar 54 containing Luxeon K2 emitters in the ratio of two red, two green, two blue, two amber and one white per "pixel".

SUSTAINABLE LIGHTING

Wind-up LED torches are a hit with communities in Malawi

Osram Sylvania has kindly donated a number of wind-up LED flashlights to Temwa, a UK-based organization that raises funds to implement community-based projects in Malawi, southern Africa. The products, providing 30 min of LED illumination after 1 min of winding, are ideal for use in areas where batteries to power conventional flashlights are a scarce commodity. Temwa's UK manager is Jo Hook, who also runs the sales activities for LEDs Magazine.

MANUFACTURING

Philips Lumileds LED plant in Singapore will double capacity

Philips Electronics is to invest an estimated $80 million to establish a high-power LED wafer-production facility in Singapore for its subsidiary, Lumileds Lighting. Philips describes the investment as part of its strategy "to strengthen its leadership position" in the fast growing and rapidly emerging power LED market.

Lumileds currently manufactures LED wafers and chips at its facility in San Jose, California, and it operates a packaging facility in Penang, Malaysia. Steve Landau, worldwide Marcom manager for Philips Lumileds, told LEDs Magazine that the new facility will be a wafer fab. "Operations in both Penang and San Jose will remain unchanged," he said.

The new plant will employ about 900 people at full capacity. Landau says that the site in Singapore consists of two buildings previously owned by Maxtor. "As such, the amount of effort and time required to bring up our processes and systems is relatively small. We expect to begin production at the facility in Q1 2007," he said. By the end of 2007, Philips expects to double its total production capacity for Luxeon power LEDs.

Theo van Deursen, CEO of Philips Lighting, said: "This investment will not only double the production capacity and strengthen our number-one position in [the power LED] field, but it will also significantly increase efficiency, supporting our aim for profitable growth."

Philips says that its Luxeon LEDs are used in what it describes as "city beautification" lighting, as well as LCD displays, camera flashes for mobile phones, and automotive and various other applications.

This is the latest indication by Philips that it is taking the solid-state lighting market seriously. Last year the company gained full control of Lumileds by purchasing Agilent Technologies' share of Lumileds Lighting for $950 million.

In the fiscal year ending July 2005, Lumileds' sales jumped 28% to $324 million, and operating profit reached $83 million. Lumileds forecast that it would have operating margins of 25% in the coming years.

Philips' global lighting rivals have also been busy. Osram has a well established vertically integrated business that manufactures LEDs and LED lighting products, and General Electric recently bought Emcore's 50% share of GELcore and announced a partnership with LED maker Nichia (p8).

NATIONAL PROGRAMS

DOE launches testing program for solid-state lighting

The US Department of Energy (DOE) has launched a Commercial Product Testing Program as part of its Solid-State Lighting (SSL) project. The program is designed to guide the planning of DOE's SSL portfolio and to foster the developing market for high-performance SSL products.

DOE will support testing of a wide, representative array of SSL products available for general illumination, using test procedures currently under development by standards organizations.

The testing program will feed back into the DOE's R&D and commercialization support activities, including ENERGY STAR program planning, technology-procurement activities, and related technology demonstrations. It will also provide unbiased, reliable product performance information to the public in the early years of SSL market development, helping buyers and specifiers to have confidence that new SSL products will perform as claimed.

The program will also guide the development, refinement and adoption of credible, standardized test procedures and measurements for SSL products. A workshop in Washington, DC, on October 27, 2006 will discuss the program.

- More details: www.netl.doe.gov/ssl.

LIGHTING

TIR partners with Semperlux and retains strategic advisors

TIR Systems has partnered with lighting fixture manufacturer Semperlux AG of Berlin, Germany – the eighth company so far to adopt TIR's LED-based Lexel lighting technology. Semperlux is one of the leading manufacturers of architecturally integrated lighting solutions in Germany and it trades under the Se'lux brand name.

TIR expects a range of Lexel-enabled lighting products to be marketed by its partners in 2007. "We are shipping low volumes of the Lexel today and remain on track to begin shipping high volumes of commercial product, manufactured by an established group of world-class contract manufacturers, by year end," said Leonard Hordyk, TIR's president and CEO.

At the same time, TIR announced that it has retained Montgomery

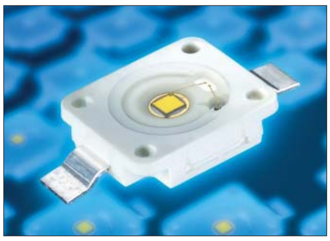
& Co to evaluate a range of strategic opportunities, in response to indications of interest regarding potential partnerships, investments or other types of transactions. Hordyk said that the industry is "beginning to recognize TIR's unique position at the center of the emerging shift towards solid-state lighting for the general 'white light' lighting market."

POWER LEDS

New Osram Platinum Dragon provides 75 lm at 700 mA

Osram Opto Semiconductors has launched the latest member of its high-power LED family, the Platinum Dragon. The new single-chip LED produces 75 lm of white light from an operating current of 700 mA, equivalent to 30 lm/W. Higher operating currents of up to 1 A can be used, depending on the color.

Osram says that the new package has the same dimensions as for the Golden Dragon, Osram's current single-chip high-power LED. However, the Platinum package can withstand twice the output and therefore a higher operating current, meaning more light in the same space.



The company says that improvements in the Platinum Dragon versus the Golden version are due to the use of Osram's high-power thin-film chip, along with better thermal connection between the chip and the package and also optimum heat dissipation of the SMT package.

Osram says that the Platinum Dragon will have a price of less than $3, which means that it offers more lumens per dollar than any other LED (around 25 lm/$ or 4 c/lm).

DISTRIBUTION

Avnet, EBV Elektronik launch specialist lighting groups

Avnet, a large US-based electronics distributor, has launched a specialist business unit, Avnet LightSpeed, to focus on the high-brightness illumination product market. The new unit, which is part of Avnet Electronics Marketing Americas, will be run by 26-year Avnet veteran Cary Eskow.

As well as distributing LEDs and high-performance analog and optical/electromechanical products, Avnet LightSpeed says that it will provide customers with access to its illumination-focused engineers. These "illumineers" are experienced in LED technology, thermal management, power driver stage and secondary optics.

Back in April, another Avnet company, EBV Elektronik, launched a similar LED lighting group in the European market-place. EBV is by far the largest supplier of optoelectronics technology in European semiconductor distribution, with a market share of more than 40%.

In EBV's view, ready-made LED lighting systems can be assembled by every experienced electrical installer, but developers and manufacturers of LED lights need the technical support of electronic specialists. EBV's General Lighting Competence Team plans to help lighting manufacturers, and their development service providers, to find optimal solutions that are usually specific to each application.

"Neon strips and energy-saving bulbs have not managed to oust Edison's light bulb from the market, and LEDs won't do it either," explained Cordula Carlin, business development manager for general lighting applications at EBV Elektronik. "Nevertheless, LEDs have an immense future in lighting applications."

EBV Elektronik sells only LEDs and other electronic components, but through its partner network it is able to place lighting manufacturers in contact with companies that can provide other services in fields such as electronic design, thermal management and visual design. "We make sure that lighting architects can convert their creative LED lighting concepts into reality by supporting the developers in realizing the appropriate control electronics," said Carlin.

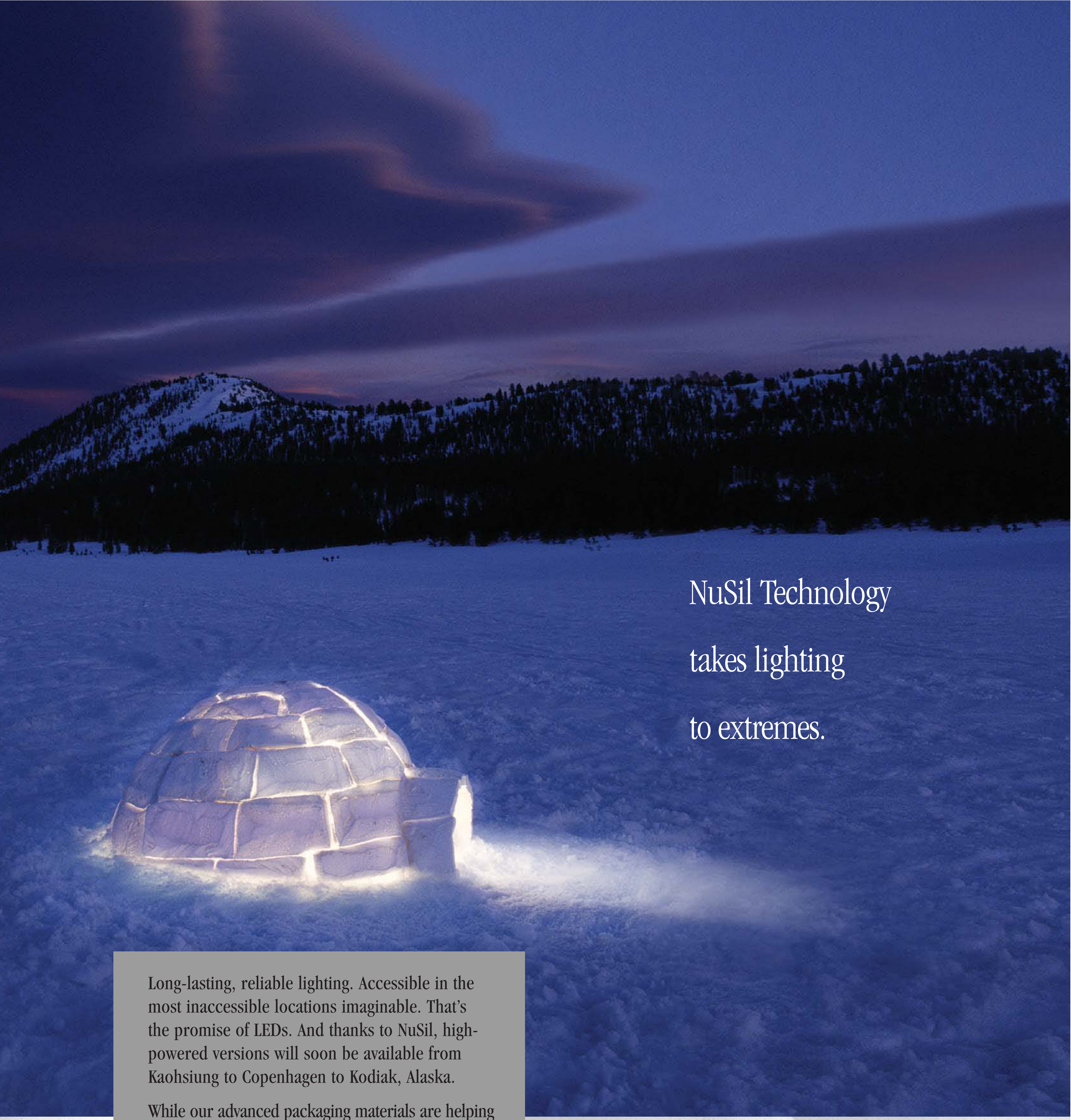
ARCHITECTURAL LIGHTING

Korean buildings make use of LED lighting effects

A number of landmark buildings in Korea have recently updated their external appearance using LED lighting, according to the first issue of a new magazine, Korea Sign Industry (KSI), published in English by POPSIGN Co Ltd. In the 63 Square building in Seoul, 1300 high-power RGB LED elements are incorporated behind opaque glass panels in the canopy above the store fronts (see photo).

Other articles on the ARCHITECTURAL LIGHTING channel of our website (www.ledsmagazine.com/articles/features/1/5/2) include:

- Optical sensor manufacturer CEDES has used more than 20,000 LEDs for internal and external lighting at its headquarters in Landquart, Switzerland.
- A high-profile advertising wall at Heathrow Airport's Terminal 3 uses LED lighting and controls supplied by Chamaeleon Technologies. The primary advertising facia of the Lightwave Wall, and the adjacent curved line of towers carrying the advertiser's logo, are washed using a total of 33 linear LED fixtures.


NuSil Technology
takes lighting
to extremes.

GE takes full control of GELcore and teams with LED maker Nichia

General Electric has bought Emcore's 49% stake in GELcore for $100 million and has also announced an alliance with Japanese LED manufacturer Nichia.

GE, one of the largest lighting manufacturers in the world, appears to be getting serious about the solid-state lighting market. GE's Consumer and Industrial Division has assumed 100% ownership of its GELcore subsidiary, a manufacturer of LED-based systems, after purchasing Emcore Corporation's 49% interest in the business for $100 million.

At the same time, GE has announced that it has entered a "strategic alliance agreement to support GELcore" with Nichia Corporation, one of the world's leading LED manufacturers. Specifics were not revealed but the companies spoke about combining GELcore's LED system strengths with Nichia's phosphor and LED products.

GE and Nichia say that they expect to benefit significantly from each others expertise and to accelerate the penetration of LEDs into the general lighting industry. GE described the agreement as a "win-win" deal that "demonstrates GE's commitment to solid-state lighting technology."

GELcore, based in Cleveland, Ohio, was established in 1999 as a joint venture between GE, one of the world's leading lighting manufacturers, and Emcore, a provider of compound semiconductor-based

Interview: David Elien, president and CEO of GLEcore

To gain further insight into GE's motives for its recent deal making with Emcore and Nichia, *LEDs Magazine* spoke to David Elien, president and CEO of GELcore, LLC.

***LEDs Magazine*: What is the significance of the timing of the acquisition from Emcore?**

David Elien: Emcore's strategy had shifted, with more focus and capital being directed towards growing its fiber optics and photovoltaics businesses. GE saw this as an opportunity to take GELcore in a different direction, and to look for new ways to improve our ability to develop LED products and accelerate LED adoption among customers.

How does the move reflect GE's strategy with respect to solid-state lighting?

GELcore's strategy for success in this space is to create high-value LED lighting solutions for new and emerging market segments, such as general illumination, while driving shareholder value by optimizing our return on capital. We feel our alliance with Nichia allows us to leverage the inherent strengths of each company in a way that positions us for long-term success.

It could be argued that, while GELcore has been successful in signage and other markets, it lags behind its competitors in the lighting market. How will it make up ground?

The strength of our business has centered on our ability to be a complete LED systems company. That focus has allowed us to take a leadership position in driving LED adoption in the segments we serve: signage, transportation, specialty and more.

The alliance with Nichia will further extend GELcore's leadership as a complete LED systems solution provider that offers extensive application-development capabilities to our customers in current and emerging market segments, such as general illumination.

What will the deal with Nichia bring to GELcore?

We formed this alliance to help us grow faster and more broadly in the $12 billion general and specialty illumination segments. The alliance combines Nichia's leadership in phosphor and optoelectronics technology with GE's leadership in traditional lighting technology to advance LED technology and accelerate the penetration of LEDs in general lighting applications. We also think we will improve our ability to develop high-value LED solutions for the signage and transportation segments.

How will GELcore and Nichia work together?

The details of the deal were not disclosed, but I will share that there are a number of investments being made on both sides. These include resource, technology, product-development and financial commitments. The fundamental objective of this alliance is to leverage our combined strengths in a way that enhances our ability to develop cost-effective LED solutions that are competitive in the market-place, and that improve our ability to drive further adoption of LED solutions in the growing general illumination segment.

When might we expect to see LED-based lighting products from GELcore?

So far this year we have launched a number of new products, including new Tetra Contour with expanded colors that replaces exposed neon in signage applications; our second-generation LED display lighting system for reach-in commercial refrigeration display units; and our GT1, next generation, incandescent-look LED traffic signal. Stay tuned because we have more on the way.

GELcore's Tetra Power White XL system uses 1 watt LEDs and has an integrated heat sink to draw heat away from the LED.

components and subsystems. Based in Somerset, NJ, Emcore is a former manufacturer of metal-organic chemical vapor deposition tools that are used to grow LED device structures.

GELcore's products include traffic lights, channel letters, and other signage and display products that incorporate HB-LEDs. It has also been developing white LEDs for the general illumination market, using UV LED chips in combination with unique phosphor blends, although these products have yet to reach the market (see www.ledsmagazine.com/articles/features/3/6/3 for more information in our report from Lightfair 2006).

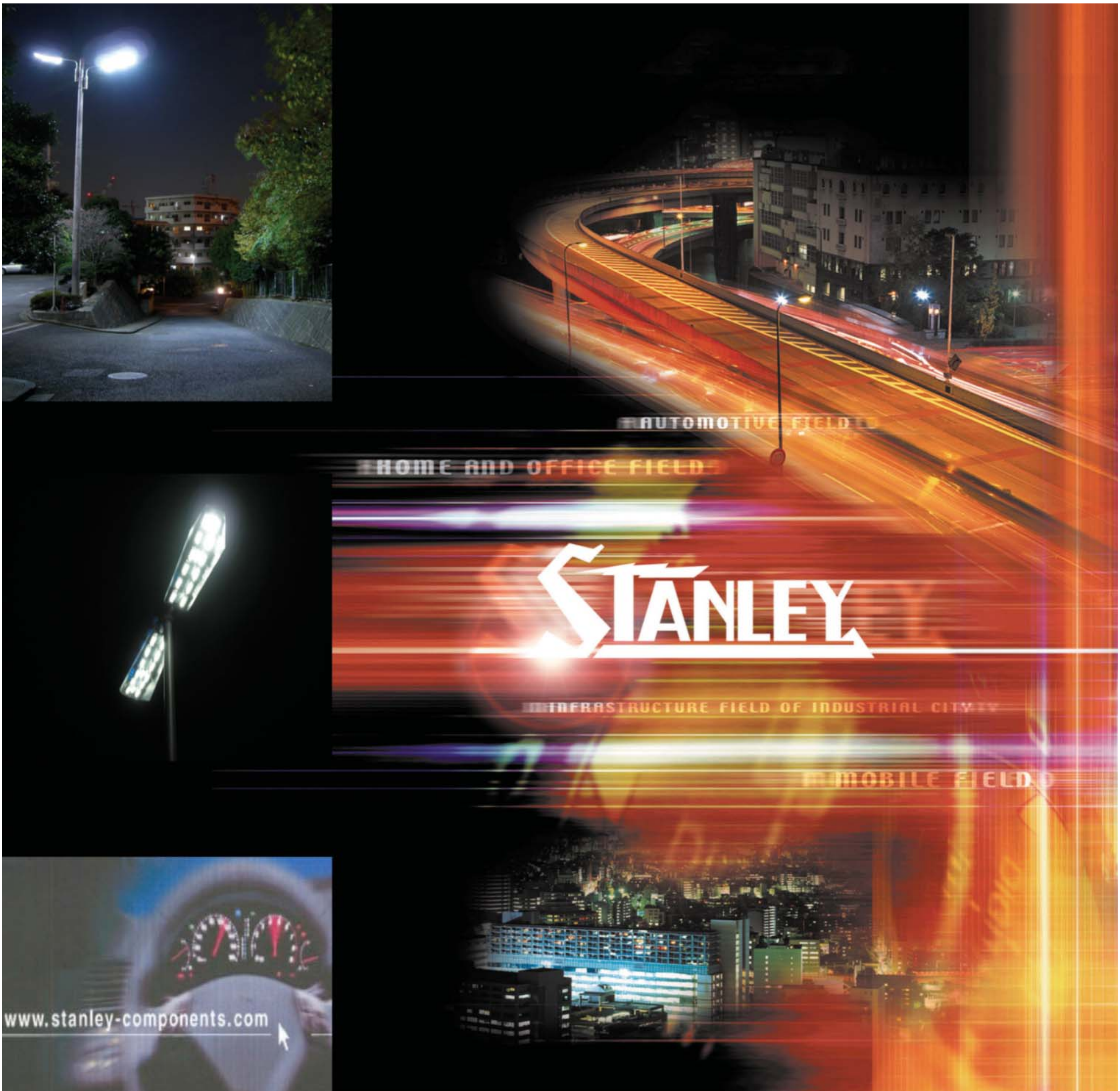
By teaming with Nichia, GE will be able to make up lost ground on its rival lighting giants, Philips and Osram. Both of these companies are now vertically integrated, to different extents, with the capability to manufacture LEDs in house and integrate them into modules and systems. Philips recently acquired Agilent's share of high-power LED specialist Lumileds Lighting, while Osram has an in-house LED unit, Osram Opto Semiconductors.

Another major Japanese LED maker, Toyoda Gosei, has formed Lexedis Lighting, a joint venture with a subsidiary of Zumtobel, a major European lighting manufacturer. The deal between GE and Nichia leaves Cree as (arguably) the most significant LED manufacturer without a formal relationship with a lighting manufacturer.

GELcore financials

In a conference call, Emcore disclosed that GELcore's revenue was \$70.5 million in calendar year 2005 and \$75.3 million for the 12 month period ending June 30, 2006. Valuing the company at around \$200 million means a multiple of around 2.7× total sales. According to John Lau of Jeffries, an investment bank, this is in line for similar valuations of publicly traded LED-related companies, such as Cree and Daktronics.

Emcore also says that its cumulative share of losses since GELcore's formation through June 30, 2006 was \$16.1 million. In 2005 GELcore recorded a net loss of \$0.8 million, compared with a \$2.5 million net income in 2004. For the six months ending June 30, 2006, GELcore recorded a net loss of \$1.3 million.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On the verge: LEDs are ready to challenge incumbent light sources in the streetlighting market

Streetlighting is fast emerging as a potentially strong market for LEDs, particularly now that devices have reached a level of output and efficiency that make them viable replacements for incumbent lighting technologies, writes **Tim Whitaker**.

In common with a number of other lighting applications, LEDs are now starting to challenge conventional lamp technologies in the streetlighting arena. A number of test installations are dotted around the globe to evaluate both the performance of the fixtures and the reaction of both lighting professionals and the general public.

LEDs offer several compelling advantages over other lighting solutions, such as the prospect of reduced energy consumption, fewer expensive maintenance call-outs and enhanced light quality. However, inevitably, there are several hurdles that need to be overcome, not least of which is the higher initial cost of LED luminaires and the general inertia of potential customers.

According to Gunnar Moos, marketing manager for general lighting at Osram Opto Semiconductors, using LEDs for streetlights offers a number of benefits. One is longer and more predictable service intervals, leading to significantly reduced maintenance costs. When high-intensity discharge (HID) lamps break, they have to be replaced very quickly in public areas, and often the local authority will have a maintenance schedule where all lamps are replaced even if they are still functional. A related advantage is enhanced safety for the road user, resulting from the high reliability and long lifetime of the devices.

LEDs also offer the opportunity for dimming to adjust to specific ambient light levels via a feedback loop, as well as flexibility in terms of luminaire design and in areas such as color temperature and color rendering. "As a whole, these advantages will ultimately result in a cost-of-ownership reduction for an intelligent LED solution compared with conventional lamps," said Moos.


PHILIPS DESIGN

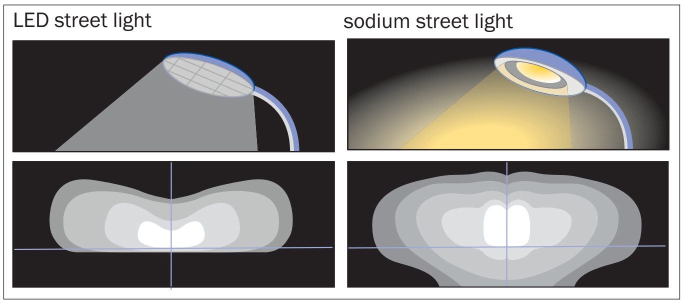
Philips CityWing Pedestrian LED fixtures illuminate a street in the Netherlands city of the Hague. Six fixtures have been installed following a similar project in the Dutch town of Ede (see www.ledsmagazine.com/articles/news/2/7/16). The poles each hold two luminaires containing 18 Luxeon LEDs. A mixture of white and amber LEDs enable warm-white light at a color temperature set in the factory. Bram Lansink, application manager outdoor and LEDs for Philips Lighting, says that the luminaires were chosen because of their innovative nature and to build up knowledge of using LEDs in public spaces. "The design and maintenance factors were also strong reasons to use the LED luminaires," he added. He says that the CityWing luminaire is most suitable for pedestrian areas and is not appropriate for roadway lighting because other sources offer greater output and are more energy efficient. "However, with the growth in lumen output and efficacy, the move to road lighting with LED luminaires can be expected from 2008/2009 onwards," he said. Before then, projects such as this one are important in adding to the experience of working with LEDs in this type of application.

Conventional technology

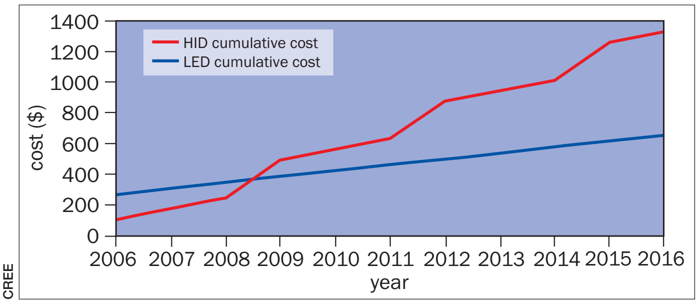
At present, streetlights generally utilize HID lamps of various types. Low-pressure sodium lamps are the most efficient, ranging from 120 to 200 lm/W, but they produce monochromatic yellow light so color rendering is extremely poor – the color rendering index (CRI) is zero. High-pressure sodium (HPS) lamps have lower efficiency (80–120 lm/W) and a similar lifetime of around 12,000 h, but better color rendering with a warm white appearance and a CRI of 22–75. Metal halide lamps are less efficient but have a very good CRI.

Almost all filament-based and gas-discharge lamps used in streetlighting provide light in all directions, so reflectors are required to shape the light output of the fixture. In excess of 65% of the available light output is lost due to inherent inefficiencies in the reflector system, and losses also occur when the light passes through the glass case that houses the HID lamp. LEDs with appropriate optics can be made highly directional, leading to drastic reductions in light loss and high system efficiency, as well as reducing light pollution.

So, although individual LEDs are likely to have a lower efficacy than HID lamps, the system efficacy (which is, of course, crucial) can be much higher, leading to lower power consumption. US lighting manufacturer MoonCell supplied its LED fixtures to the Michigan



STANLEY ELECTRIC



CREE

Comparison of lighting patterns from LED and sodium streetlights. The focused nature of the LED system places light on the roadway and also drastically reduces light pollution.

Although LED fixtures are more expensive at the outset, the cumulative cost of HID fixtures rapidly increases and a crossover occurs after 2.0–2.5 years.

Department of Natural Resources for outdoor lighting in parks and was told that "the 79% cost savings in energy maintenance [of the LED fixture], over the 250 W HPS fixture that it replaced, is just what we were looking for". Improved light quality, making it easier for staff to look at visitors' documents, as well as reduced light pollution, were also cited as advantages by the customer.

Light quality and specifications

LED lighting manufacturers would argue that the quality of light from LED lighting fixtures is significantly better than that from other streetlighting technologies, providing better visual acuity and color rendering. Improved color recognition provides contrast and increases depth perception, and CCTV images that are recorded using LED lighting are much clearer. LED light produces less glare and fewer reflections, and it cuts down on the light pollution that is associated with other light sources. There is also the related psychological benefit of making people feel safer.

The improvements in light quality occur because in low light conditions the human eye is much more sensitive to shorter wavelengths of light, rather than the yellow/orange light emitted by many HID lamps. In photopic vision, which occurs in normal daylight conditions, the eye sensitivity peaks at 555 nm in the green part of the spectrum. At lower light levels, scotopic vision kicks in and the peak sensitivity shifts to shorter wavelengths. The spectrum of white LEDs, which usually con-

LEDworx tests LEDs in Dubai

LEDWORX GMBH

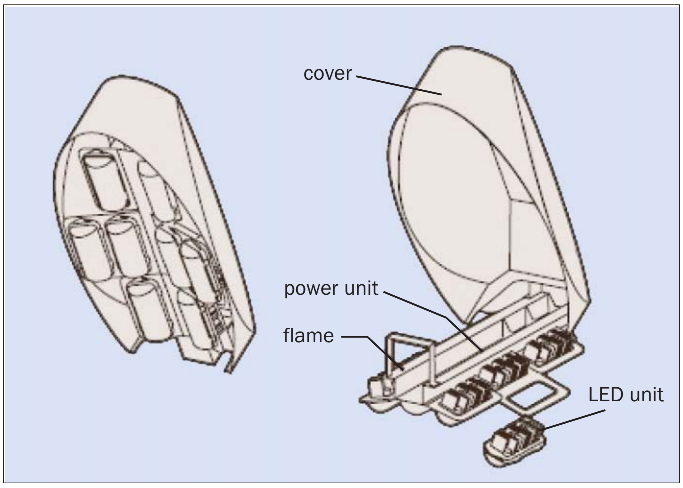
LED luminaires installed in Dubai (left) contain three linear LED modules, each with a total of 28 LEDs.

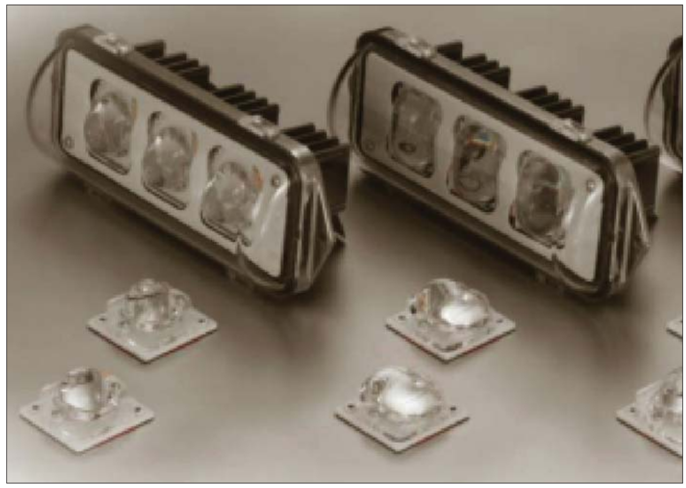
LEDworx GmbH has made a five-luminaire test installation in Dubai to allow customer testing over a three-month period corresponding to the hottest time of the year. Franz Witthalm of LEDworx says that the installation will also allow customers to become familiar with the new LED technology and to prove its reliability. The main reasons for choosing LEDs are long lifetime – which will result in significantly lower maintenance costs – as well as lower energy consumption. Witthalm says that there is also another reason: "Dubai could become the first-ever city to light its streets with LEDs."

There are a number of challenges that are specific to this installation, explains Witthalm. Most significant is the struggle against the outside temperature in Dubai, which can reach 50 °C in the shade, meaning 70–80 °C in direct sunlight. "We make the construction for 85 °C because streetlights only run for a short time in sunlight," said Witthalm. "Our product is temperature-compensated, and the LED current is reduced if the temperature gets too high." Also, fans are not used since this could counteract the lifetime benefits of the LEDs.

Another issue is light distribution. The distance between the poles is 50 m and the pole height is 8m, so an average full angle of nearly 160° was required. The LEDworx Hawk-Eye luminaire contains three linear LED modules, each of which has an emission angle of 60° and overlap achieves the necessary 160°. Each module contains four circular clusters of seven high-power white (5400 K) LEDs. A total of 84 LEDs produce 4620 lm with an efficacy of 55 lm/W, and the resulting CRI is 75.

The use of LED modules is a first step towards creating a standard for LED applications, says Witthlam, adding that LEDworx has developed control gear that can last as long as the LEDs – up to 100,000 h – and includes power factor correction.





STANLEY ELECTRIC

Stanley Electric has developed a modular approach to LED streetlighting based on removable optical units that each contain three lensed LED modules. The three-LED optical unit consumes 15.8 W with a typical current of 400 mA and produces 570 lm. Stanley says that it has used its optical semiconductor and design technology expertise to improve luminous efficiency to a level that is sufficient for numerous lamp-type applications, such as streetlighting. The company's LED fixtures are currently in use in several global locations in association with strategic partners, with encouraging feedback and results.

sists of blue LED emission mixed with longer-wavelength emission from one or more phosphors, is better matched to the eye's sensitivity for scotopic or mesopic vision (mesopic vision occurs at intermediate light levels and is a mixture of scotopic and photopic vision).

Rewriting the specifications

However, this gives rise to other issues relating to streetlighting specifications, which are quite precise as to what light levels are required for a particular area of the ground and on a particular grade of road. The problem, says Dennis Lockwood, managing director of Whiteley Electronics, is that all of the specifications are written around conventional lighting technologies. "When you measure the illuminance in lux, the meter reading tends to favor the older technologies rather than LED technology," he said.

This is because sodium lamps and other light sources emit large amounts of light in regions where the eye is not particularly sensitive. Even so, this light gets incorporated into the specification in terms of a high lux value. "Trying to meet a specification written for fluorescent or sodium lamps, which requires a certain lux level on the road surface, means that you've got to effectively overlight it using LEDs technology to meet those measured levels," said Lockwood. He believes that there should be some reassessment of the specifications to define what LEDs have to do, but this will take a long time.

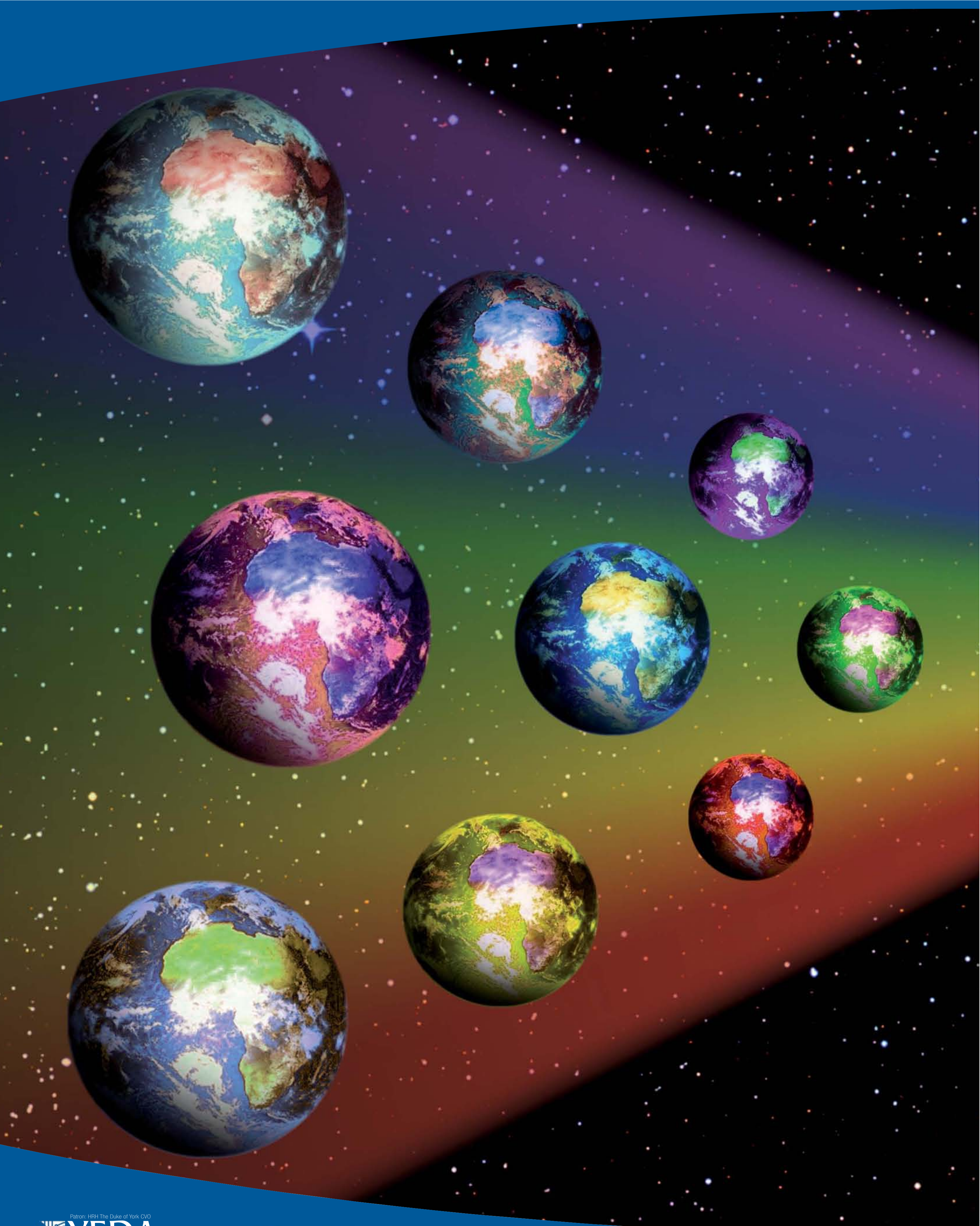
Mark Hopkins of Advanced LEDs Ltd concurred: "Further research is required into scotopic and mesopic vision ranges to enable people to design a lighting scheme with LEDs that will provide the level of lighting that we actually need. LED lighting is sharper, crisper and provides better color uniformity, and for functional outdoor lighting it makes pedestrians and roadways more visible. We need to get some lighting schemes out there to show lighting professionals the quality of light that can be achieved with LEDs."

Higher-performance white LEDs

Most LED streetlight products and prototypes use high-power white LEDs, although there are some exceptions (see box, "Different approaches"). Cree, one of the leading manufacturers of power LEDs,

WHITELEY ELECTRONICS AND CONSTELLATION LIGHTING LIMITED

These LED fixtures from Whiteley Electronics contain arrays of high-power white LEDs with individual lenses. The firm provided LED lighting to Sheffield United FC, an English football club recently promoted to the top league that required improvements to its facilities, including a new lighting scheme for its main car park. Whiteley supplied its Jupiter48 AC LED light, which is designed specifically to illuminate roads, car parks, pathways and public areas. This 48 W mains-powered LED light contains 48 white LEDs with individual optics, and it reduces energy consumption by up to 75% compared with traditional lighting methods.



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Different approaches

Reflector optics

While many LED streetlighting luminaires use high-power white LEDs either with or without individual lenses, Advanced LEDs has developed a system using patented reflector optics to achieve the necessary output and distribution patterns. "A well designed reflector results in fewer losses than using lenses or other optics," explained Advanced LEDs' Carl Clarke. "A reflector system also removes any issues of potential eye damage from staring into a lensed array of high-power LEDs."

Clarke says that his company has achieved its mission statement of a light fitting measuring 450 x 300 x 100 mm that has a "real-world" thermal rating of 0.17 °C/W utilizing passive cooling. "Our 60 W, 2500 lm streetlight operates at a junction temperature of 40 °C and has a lifetime of 60,000 h at full power and 230,000 h at half power. The electrical efficiencies are greater than 90%," he said. The standard power LED product range of 60–400 W is now available and carries a 10 year warranty. Also in the range is a solar-powered option at a lower wattage.


ADVANCED LEDS

NEOPAC LIGHTING

Low-power emitters

Rather than use high-power LEDs, Ledtech of Denmark has a different approach, which is to use 5 mm warm-white LEDs with a color temperature of 4000 K, driven at 20 mA. Streetlighting products are built around panels containing 84 LEDs – the six-panel version with 504 LEDs has a power consumption of 42 W and produces 2436 lm, with an efficacy of 58 lm/W. Lars Kjaer of Ledtech says that it is better to use 5 mm LEDs due to thermal issues. "We cannot control the heat in high-power LEDs when we have to get to 2500 lm," he said. The LED fixtures are intelligent, so it is possible to see which streetlight and LED panel need servicing at any time. There is also a half-power capability as well as just "on" and "off". Kjaer says that there are several text facilities using LED streetlights in Denmark and others in Dubai and Italy.

RGB LEDs

Arizona-based Enlux Lighting exemplifies yet another approach, which is to use RGB LED technology. The company's 6 K Series OutdoorArea Lights are based on Enlux-patented chip-on-board light engines, each comprising a cluster of red, green and blue chips. A total of 64 chips yield an output of 300 lm per light engine. Model 614203 contains eight light engines and produces 2400 lm, with a total power consumption of 100 W for the entire system. The color temperature is 4100 K and the light has a list price of $899.

White-light engines

Taiwan's NeoPac Lighting has built a 135 W NeoBulb Street Light to showcase its capability of designing an outdoor lighting device that can maintain a low and uniform LED junction temperature of 60 °C. The luminaire contains 18 NeoPac Emitter light engines, each containing six power chips (1 × 1 mm) mounted on the company's thermal management scheme, and they are driven at 7.5 W.

NeoPac plans to offer three types of outdoor lighting device (120, 60 and 40 W) containing an appropriate number of eight-chip light engines driven at 10 W. Jeffrey Chen, NeoPac's president, says that the company will launch the 120 W NeoBulb in Q4 of 2006. "Our target is to replace traditional 400 W streetlight lamps with an energy saving of 70%, as long as the LED efficacy is improved as expected," he said.

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thinks that a recent surge in interest in LEDs for streetlighting is due to LED performance improvements. "We think that the market has been triggered by Cree and at least one other competitor having pushed through a 'lumen threshold' of being able to offer power LEDs that produce 50–55 lm," said Mark McClear, Cree's director of marketing and applications development for solid-state lighting. "This makes the business case possible for LED streetlighting. It's nice to demonstrate light output and technical possibilities, but once the economics work then the market can really start to take off."

McClear says that he discusses with customers the comparison between LEDs and HID lamps using a model with several adjustable parameters (as shown in the graph on p12). LED fixtures have a higher initial cost than HID luminaires, but a crossover in cumulative cost happens after a little more than two years. The only ongoing cost of the LED fixtures is energy usage, which is lower than that for conventional lamps. Even more significant is that there are a series of large steps for every "maintenance event" whenever the HID lamp has to be replaced. "Data from municipalities and power companies indicate that it costs more to change the lamp than it does to pay the initial cost of the HID fixture," said McClear.

Of course, the improved light output of latest-generation LEDs affects the economic argument. If the LED produced only 40 lm instead of 50–55 lm, the fixture would require more than 100 devices instead of 60–70 to provide the same amount of light. This makes the cost of the LED fixture prohibitively high and would also make the fixtures much larger than a conventional luminaire.

Cree's current model assumes a price of $2.50 per LED. "The lumens-per-dollar metric has been increasing at about 30–40% a year, and we don't see an end to that trend," said McClear. This is driven both by improved lumen output and by price reductions. Cree is bullish about LEDs for streetlighting, adds McClear, and further LED performance improvements, due to be announced imminently, should catalyze interest from the major streetlighting manufacturers.

Cost and other challenges

Even with such attractive payback calculations, getting potential customers to take notice is not an easy job. Whiteley's Lockwood feels that the take-up of LED streetlighting, even with its associated energy-saving benefits, could require government intervention. "We've contacted more than 1000 local authorities and they're very slow to get involved," he said. "Some local authorities have franchised out the supply and maintenance of their streetlights for the next 10 years, but crucially the authority still has to pay the electricity bill. In that situation, the franchise operator will purchase the cheapest fittings and has no interest in power savings. The local authority is stuck with an ever-increasing energy bill as costs go up."

Issues like this could prove to be the major challenge for LEDs. Manufacturers claim that most technical issues are within their reach, even though LED fixtures do not currently quite meet the specifications for the most demanding types of roadway. As well as the difficulty of introducing a new technology into an established market, Osram's Moos says that there will also need to be some degree of standardization. "We see a major challenge for LEDs in the streetlighting market as being standardization and long-term replaceability of LED-based modules," he said. Although LEDs have a long lifetime, there is no way to replace the LEDs in most systems except by replacing the whole fitting.

In future, streetlighting could benefit from intelligent control, using LEDs to adjust the amount and distribution of light. An obvious example is to reduce the amount of lighting provided to a busy roadway when there is much less traffic than normal. Also, an intelligent system could adjust the light pattern to take into account reflections from the road surface caused by standing water, or to reduce glare in foggy situations.

And we still haven't mentioned a potentially huge advantage of LEDs: their compatibility with solar power and photovoltaic systems. Relying on solar power rather than mains electricity means that installation costs are significantly reduced (e.g. there's no longer the need to dig up roads to install cabling) and, of course, there should be no ongoing energy costs. Units are robust, they're resistant to vandalism and they can be designed as self-contained units that require minimal maintenance.

Carl Clarke, managing director of Advanced LEDs, emphasizes that LED streetlights are available now. "We are selling units, mainly outside of the UK, and we have photometric files that demonstrate to local authorities that LED light sources are a direct and viable replacement for existing technologies."

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Six-color mixing and warm-white/green/blue offer new approaches to generating white LED light

Light-emitting diodes are so beguilingly simple that we sometimes overlook the obvious when designing solid-state lighting systems. **Ian Ashdown** and **Ingo Speier** of TIR Systems take another look (or two) at generating white light.

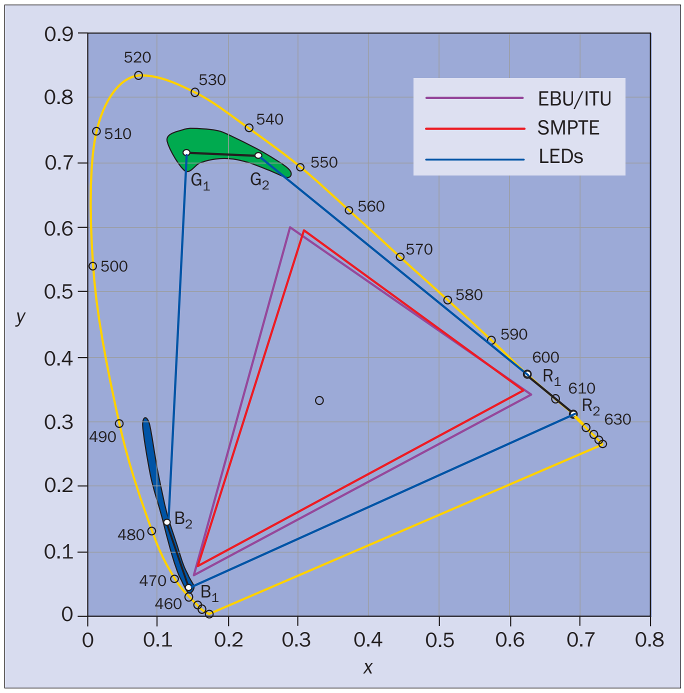

Fig. 1. LED color binning for LCD television backlighting.

It has been said that LEDs are "just another light source" and in many senses this is true. Like the more traditional incandescent, fluorescent and high-intensity discharge lamps, LEDs do no more than convert electrical power into visible light and heat.

This observation may be useful in demystifying LEDs for lighting designers and engineers who are learning about solid-state lighting. However, it comes with a hidden danger. If we repeat the phrase often enough, the idea permeates our thinking about solid-state lighting design. In turn, this may cause us to neglect the unique attributes of LEDs and so overlook the obvious in our problem solving.

Two examples serve to illustrate this point: a solution to the problem of color-binning of LEDs for LCD television backlighting, and an approach to generating white light with variable color temperature.

LED backlighting for television displays

High-flux LEDs are currently being used to provide backlighting for LCD televisions, with a projected penetration of 25% in a market estimated to be worth $72 billion a year by 2010 [1]. In comparison with the cold cathode fluorescent lamps (CCFLs) currently in use, LEDs offer longer life, environmental friendliness (they're mercury free) and enhanced color gamuts.

Compared with fluorescent lamps used in architectural applications, CCFLs have some unusual design requirements. First, they should have a correlated color temperature of 6500 K, which is the industry-standard "white point" for color television displays. Second and more important, their spectral power distribution (SPD) should exhibit peaks at approximately 455, 545 and 615 nm.

The reason for these unusual SPDs is that the white light from the CCFLs is filtered by triads of red, green and blue microfilters, one for each pixel. Any light outside the bandpass regions of these filters is simply absorbed.

The narrowband emissions of red, green and blue LEDs appear to be ideally suited for this application, but there is a catch. The chromaticities of these three "primary colors" are specified by broadcast television standards, with very stringent limits on any variations [2-4]. Translated into dominant wavelengths, these limits are 2–16 times as stringent as current color-binning practices for high-flux LEDs.

One obvious solution is to perform more-careful color binning. However, this results in poor yields and hence more-expensive LEDs, a problem that will only be compounded by LED die and packages designed expressly for backlighting applications.

A much better solution is to delve into color theory and consider the laws of color additivity, first published by the mathematician Hermann Grassman in 1853 (see box, "Grassmans's laws of color additivity"). These laws should be familiar, because they describe the fundamental principles of RGB color mixing. They also hold a novel solution to our problem.

Binning: the six-color solution

Grassman's laws are best understood in the context of the CIE 1931 chromaticity diagram. By plotting the chromaticities of the SMPTE (North American) and EBU/ITU (European) television primary colors on this diagram (figure 1), we can immediately see the range of colors – the color gamut – that can be achieved by television displays in accordance with Grassman's first law.

It is, however, the second law that is the most interesting. Figure 1 also illustrates the typical range of chromaticities for high-flux red, green and blue LEDs. If, for example, we have green LEDs with chromaticities G1 and G2, we can blend their output to attain any color whose chromaticity lies on the straight line connecting G1 and G2. We can do the same with blue and red LEDs.

When you see this graphical representation, the solution becomes obvious. By using pairs of LEDs from different color bins and appropriately blending their light, we can achieve precise control over the color gamut [5]. With this solution, we also have no need for precise color binning.

There is yet another advantage to this six-color solution. If we can control the relative drive currents to the LED pairs during operation, the system becomes essentially temperature independent. Even if the LED peak wavelengths shift with changes in junction temperature, the chromaticities of the primary colors can be held constant.

Is this solution obvious? With the benefit of hindsight, perhaps. Nevertheless, it shows that we have not yet realized the full potential of LEDs for solid-state lighting.

Variable CCT white light

One of the advantages of solid-state lighting is that architectural luminaires can be designed to generate white light with variable correlated color temperature. This has been done with commercial products using either a combination of warm white and cool white phosphor-coated LEDs (pcLEDs) or RGB LED clusters. There are advantages and disadvantages to both approaches:

- **Energy-efficiency** RGB LED clusters typically exhibit higher luminous efficacies (lm/W) than pcLED combinations for color temperatures below 5000 K.
- **Optical feedback** Unlike pcLED combinations, RGB LED clusters require optical feedback to prevent objectionable color shifts with changing LED junction temperatures.
- **Color rendering index (CRI)** pcLED combinations offer better color-rendering capabilities than RGB LED clusters.
- **Color shifts** Unlike RGB LED clusters, pcLED combinations have color shifts of eight MacAdam ellipses off the blackbody locus at 4000 K, resulting in pinkish white light.
- **Temperature dependencies** Unlike RGB LED clusters with optical feedback, pcLED color shifts cannot be corrected.
- **Phosphor degradation** Most phosphors exhibit long-term degradation, so pcLED chromaticities shift towards blue over time.

These and other issues regarding pcLEDs versus RGB LEDs have been discussed elsewhere [6]. The CRI issue can be addressed by including amber LEDs in the LED cluster, and amber LEDs can be used to compensate for color shifts with pcLED combinations. However, amber LEDs have severe nonlinear temperature dependencies (80% decrease in light output at 100 °C junction temperature versus 25 °C), so both of these approaches need both optical and thermal feedback to prevent color shifts.

The warm-white/green/blue approach

We are familiar with mixing red, green and blue to create white light (or blue and yellow for phosphor-coated LEDs), but these are not the only options. We can also, for example, use warm-white, blue and green LEDs.

This may seem odd at first, but it makes sense if you look at the resultant color gamut on the CIE chromaticity diagram (figure 2). It encompasses the black-body locus above the color temperature of the warm-white LED, so any color temperature above this can be achieved.

It gets better. Whereas the combination of warm-white and cool-white pcLEDs has an average LED utilization of 50%, it takes relatively little green and blue light to generate different color temperatures. In fact, it takes only one green and one blue LED for every five warm-white LEDs. Further, the warm-white LEDs have on average 100% utilization.

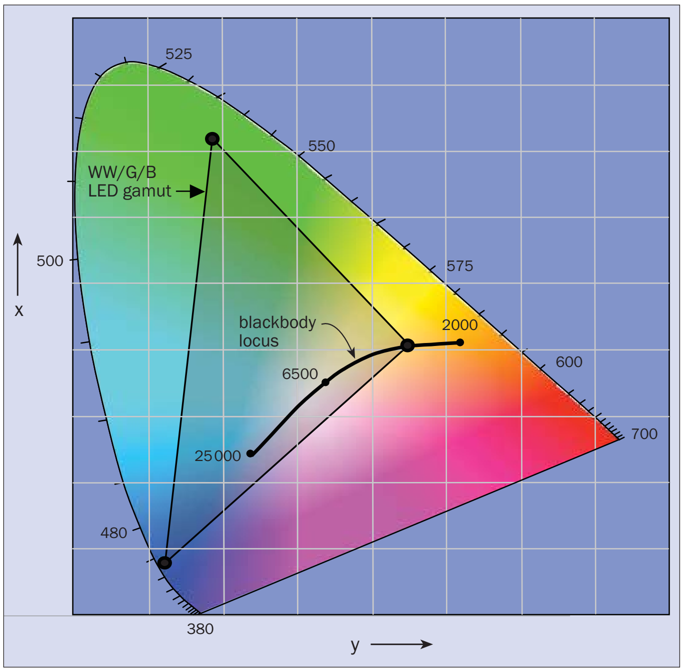

Fig. 2 The warm-white/green/blue approach for creating white light.

By themselves the warm-white LEDs exhibit CRIs of 85 and more, which is better than many fluorescent lamps. Adding small amounts of green and blue light actually improves the CRI, reaching 95 at 4000 K.

With the warm-white LEDs being operated at essentially constant power regardless of the color temperature, the problem of color shifts due to phosphor temperature dependencies is greatly reduced. (These shifts, however, may occur if the luminaire is dimmed.)

Finally, the color-binning requirements for the blue and green LEDs are minimal because their varying chromaticities are easily compensated with optical feedback.

It is possible that this WW/G/B approach can be implemented using only thermal feed-forward techniques for applications that do not require precise color control. However, it remains to be seen what the long-term degradation of warm-white LEDs will be. With new red-emitting phosphors constantly being developed, it is difficult to design reliable analytic models for feed-forward operation.

A different light

The lesson here is not the examples themselves but that LEDs are much more than "just another light source." We are perhaps too familiar with LEDs and color mixing. It is not their simplicity that is important but our ability to look beyond common knowledge and see them in a different light.

Further reading

[1] Now showing on a television near you: LEDs are the ones to watch, Strategy Analytics, May 2006.
[2] SMPTE, SMPTE C Color Monitor Colorimetry, SMPTE Recommend Practice 145-2004, Society of Motion Picture and

Grassmans's laws of color additivity

The laws of color additivity, which describe the fundamental principles of RGB color mixing, are as follows:

First law: any color, C ,can be matched by a linear combination of three other colors, R, G and B.

$$C = aR + bG + cB$$

where a, b and c are constants with $a + b + c = 1$.

Second law: any two colors, C_1 and C_2, can be blended to generate a third color, C.

$$C = dC_1 + eC_2$$

where d and e are constants with $d + e = 1$.

Third law: the blended colors remain the same at all brightness levels within the range of color vision.

$$kC = k(dC_1 + eC_2)$$

where k is a constant of proportionality.

Television Engineers, White Plains, NY, 2004.
[3] EBU, E B U Standard for Chromaticity Tolerances for Studio Monitors. Technical Publication 3213-E, European Broadcasting Union, Geneva, Switzerland, 1975.
[4] ITU, Basic Parameter Values for the Studio and for International Programme Exchange, ITU-R Recommendation BT.709, International Telecommunication Union, Geneva, Switzerland, 1990.
[5] I Ashdown et al. 2006 "Binning and filtering: the six-color solution," Proceedings of Solid State Lighting VI, SPIE 6337.
[6] I Speier et al. 2006 "Color Temperature Tunable White Light LED System" Proceedings of Solid State Lighting VI, SPIE 6337.

About the author
Ian Ashdown (Ian.Ashdown@tirsys.com) and Ingo Speier are with TIR Systems Limited (www.tirsys.com), Burnaby, BC, Canada.

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LEDs MAGAZINE

Automotive lighting design with LEDs puts the 'super' into the Ford Super Chief concept vehicle

A variety of innovative LED lighting designs have been implemented on Ford's recent concept vehicle, and these could soon appear on production vehicles, according to lighting designer **Robert Miller**.

Figure 1. The front of the Ford Super Chief concept has white LED forward and fog lights, as well as amber "transparent chrome" running lights on the roof. The front indicator and door handle lights are made with LED light guides. The rear features horizontal light guides, as well as multiple LED brake light units on the roof.

Concept lighting poses significant challenges to any automotive designer. It also poses a challenge to the person who is tasked to create this lighting and bring it to life. When Ford created the 2006 Super Chief concept vehicle, it insisted on the most advanced LED technology to "push the visual appeal" to the highest level. The implemented lighting technology had to be in line with reality, and likely to appear on production vehicles within several years. The challenge was to infuse new LED and light-management technology into the vehicle, creating visual interest and stimulation.

Exterior and interior lighting is becoming much more sophisticated and often has several unique visual elements operating simultaneously. Customers who view concept cars are often heard to say: "Great ideas and looks, but it never seems to find its way in to real cars." The key is to blend new "eye candy" features with real design and production-worthiness, using the latest LEDs and the most innovative light-management technologies available. Together, all of these elements create visually interesting products with lighting that greatly enhances the overall vehicle design.

From its exterior statement, the design of the Super Chief firmly cements together the image of beauty and sophistication that draws the consumer into the entirely new look and feel of this vehicle. Innovative lighting – for example lighting areas on the vehicle that you would never expect – further instills visual interest.

The use of "transparent chrome" that suddenly comes alive with color when energized by LEDs achieves just such a "stealth" lighting effect. This look was one of the most commented-on elements of the exterior lighting and was very popular with the public. These lighting statements were used in the amber running lights on the roof of the vehicle, the wing mirrors and the roof-mounted rear brake-light (CHMSL) areas.

Roof lighting kept under glass

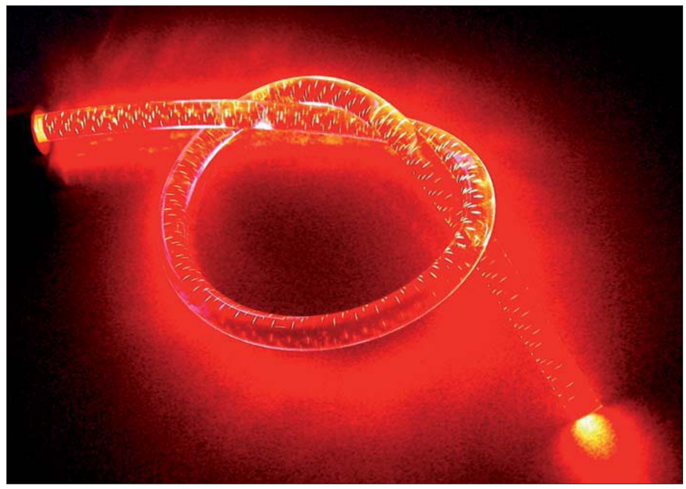
Making this lighting design even more spectacular are the high-brightness LEDs located under the glass roof, which dominates the entire top of the vehicle. The LEDs were located inside the vehicle, with fret lines positioned to allow light to pass through the glass directly to the transparent chrome bezels. The bezels were placed on the outside surface of the glass (figure 2a). The result is a clean, simple design with full protection of the lighting module, and the brightness is controlled using a tunable electronic LED driver.

Another area where transparent chrome is utilized is in the wing mirrors, which contain amber turn indicators (figure 2). In the off state the mirror edge looks like chrome, but when the turn signal or running lights are energized the chrome surfaces come alive with amber light.

A similar approach is used for the rear lighting, which uses custom LED light-management optics. The entire lighting area emits a smooth, even light with absolutely no hot spots in any of the displays (figure 1). This look was achieved with light guides from iLight

Figure 2. Stealth lighting using transparent chrome. Left: one of several chrome bezels placed on the outside front of the glass roof. The LED lighting is beneath the glass. Middle and right: wing mirrors with amber LED indicators.

Figure 3. Door handles containing a custom-made LED light-guide are a hugley popular feature of the Ford Super Chief concept.



3M's Precision Lighting Element material emits LED light over lengths of up to 4 ft, even when tightly bent.

Technologies with a series of modifications, including the use of high-power LEDs to increase the lumen output. The resulting effect dazzled viewers with light that looked bright and even, and that exhibited a three-dimensional appearance.

The Ford Super Chief has four beautifully designed chrome door handles that beg to be touched. At autoshows we often saw people reaching out to try to touch them while the vehicle slowly rotated away from them. We were asked by Ford Design to make the handles amber in color, and to create a light-management optic that was bright and had an even, diffuse output. We decided on a matt finish so that the amber light would contrast with the shiny chrome of the door handle.

This posed significant design challenges, which we overcame by using 3M Vikuiti series of films and LEDs supplied by Osram Opto. In essence we created a very efficient precision light guide that worked in a very small area. Some people actually thought that it was neon, achieving one of our goals for this fixture.

Forward lighting

For forward lighting it was decided to use LEDs with the most unique style available. We needed LEDs that were bright and emitted a cool white 6500 K temperature output. Ford's mission was to create a truck with a "bold visual statement" and ours was to involve lighting in that design. Very large lenses that complement the front design of the vehicle represent the future design direction that Ford wished to implement with the Super Chief.

The task was to somehow deliver more than 1600 lm of light output, as well as color and visual interest in both the "on" and "off" states. We decided on Lamina Ceramic's BL-2000 seven-cavity light engines, because these LEDs provide the required visual interest when the lights are off. We used eight light engines for each side (16 in total), clustered into four groups. Each group of four was mounted on a heat sink and had a specially designed optic containing four lenses (figure 4). The optics were milled out of solid 8 × 6 inch blocks of acrylic and each took almost 60 h of milling and polishing time.

For the turn signals that appear in the middle of each headlight, we utilized the same neon-like appearance as found in the door handles, tying the two visual elements together.

Another assignment was to design a thermal management system for the lights that would become the focal point for the back side of the hood and would complement the inside design of the engine compartment (figure 5). Ford designers not only wanted to see the heat sinks but also wanted them to be beautiful. We accomplished this by taking the designers' initial thoughts and renderings and then modeling and applying our own designs to make the lights a reality.

For the fog lights we custom-designed four units (figure 6) that were joined together to create two sets, one for each side of the vehicle. Four

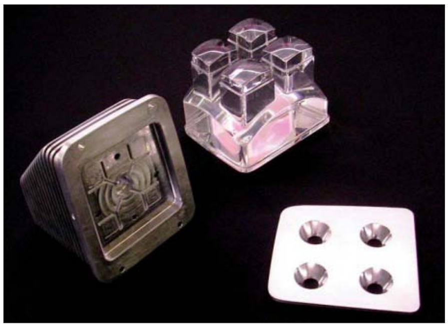


Figure 4. Heat sink block, lens block and reflector for high-power LED headlights.

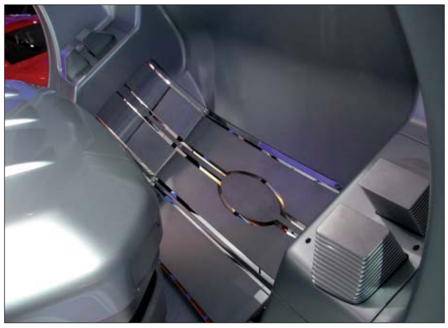


Figure 5. Interior of engine compartment, showing the four headlight heat sinks.

Figure 6. White LED fog light units using Osram Ostar Projection LEDs.

Osram Ostar Projection LEDs were used to closely match the 6500 K output of the BL-2000 LEDs, so that all of the lights would be uniform in color. We built a dimmable electronic driver so that any brightness level could be dialed in for any type of situation. The end result was spectacular forward lighting showcasing the boldness and robustness of the Super Chief design.

The future of light management

We are likely to see an explosion of new lighting applications and ideas in future concept and production vehicles. Light-management materials such as 3M's Precision Lighting Element (PLE) material, will dominate future designs. PLE material is unique and flexible, and it emits LED light over lengths up to 4 ft – better than any other technology to date. Even when it is tightly bent, the light is constant and uniform. 3M successfully developed a proprietary material and a unique way of microreplicating the light-ejection slots on this material for efficient, beautiful light management. The company suggests that it may be possible to customize the ejection slots with other designs to offer different looks, texture and light-output options. This will open up many new branding opportunities for vehicle OEMs.

Summary

Ford's 2006 Super Chief was a complete success and did what concepts are supposed to do – turn ideas into reality. Expect to see lighting that emulates what was done on the Super Chief in future concepts, as well as in production vehicles in the not-so-distant future. Controlling and giving light a "personality" that lives in the space of a vehicle is a trend that designers are working towards.

Considering whether LEDs will grace the entire vehicle, it's not a question of if but when. As LEDs become brighter and more cost-effective, parallel improvements are required in light management and techniques needed to differentiate design tastes. Concepts drive production, so you should see some very exciting lighting designs appearing in the next series of international autoshows.

About the author

Robert Miller (tel: +1 734 255 0300, e-mail: lightjet@mindspring.com) is a consultant and former owner of BrightLights Technologies, LLC. He has successfully designed and delivered more than 100 advanced lighting programs and completed in excess of 20 complete automotive concept vehicles over the last 10 years. Along with his automotive lighting design experience, he has successfully created many other innovative lighting products from flashlights to track lighting utilizing advanced LED technologies.

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Integrated optimization capabilities provide a robust tool for LED backlight design

LEDs offer many advantages for LCD backlighting, but designing the light-guide extraction features is difficult. **Michael Zollers** of Optical Research Associates, says that this is why an illumination design and analysis software package is essential.

Times are changing for liquid-crystal display (LCD) backlight designers. An old technology is coming of age and creating a myriad of benefits for the end user, from brighter displays with more vivid colors to longer battery life for portable devices. This technology is the LED.

Following their success in mobile phone handset applications, LEDs are fast becoming a viable option as the light source in larger LCD screens. In September, Samsung unveiled a 40 inch LCD television with an LED backlight, providing a much wider color gamut than competing models (see www.ledsmagazine.com/articles/news/3/9/6 for more details).

LEDs have been around since the early 1960s but, until recently, they haven't been useful for LCD backlights because of low luminance and the lack of a white spectrum. LEDs have several advantages over the cold cathode fluorescent lamps (CCFLs) that they are replacing, as follows:

- they can consume less power by eliminating the need for a ballast, thereby increasing the on-time for battery-operated devices;
- they emit into a hemisphere (as opposed to the CCFL's full sphere), so it is easier to couple LED light into the light guide efficiently.
- they have a different spectrum from that of CCFLs, which can result in a broader color gamut.

There is, however, at least one drawback to using LEDs for LCD backlights: it's more difficult to design the light guide extraction features. CCFLs are relatively large and linear, which means that their extraction-feature patterns are roughly linear in one dimension. LEDs, however, are small and discrete in nature, so their extraction patterns need to have structure in two dimensions.

"The combination of virtual prototyping and optimization allows the designer to create better-performing designs while reducing time to market."

This complicates light guide design, which is often done through a tedious and expensive trial-and-error process. A designer lays out a pattern, creates a mock-up, tests it, makes modifications based on the results and then repeats some of these steps, if necessary. A more practical approach relies on illumination design and analysis software packages, many of which have design and analysis tools that are useful for backlight designers.

Software is good for quickly creating a virtual prototype, analyzing it and refining the design based on the results. In some software packages it is now possible to run automatic optimization routines that make improvements to a design without user intervention. The combination of virtual prototyping and optimization in illumination design software allows the designer to create better-performing designs while reducing time to market.

To illustrate the use of software in the design of LCD backlights, the following example was created: a 4 inch diagonal, 16:9 LCD that is backlit with white LEDs.

The first step in this design is to determine the type, quantity and placement of the LEDs around the light guide. Often, one or more of these parameters is determined by electrical or mechanical constraints. For this example the Osram Micro SIDELED was chosen. This has a small, uniform emitting area, which should produce reasonable results with a simple or complex source model. I used two LEDs, placed on opposite sides of the long edge of the light guide, one-third of the distance from the short edge. There may be a more optimum placement, but this arrangement serves as a good example because it makes a somewhat complex extraction-feature pattern.

In software it's necessary to create a model of the source. The simplest model could be just a planar surface with rectangular bounds that emits white light with the correct spectral distribution. It should include the correct angular and spatial emission. The most accurate model would contain a cubic die that emits blue light into a yellow-phosphor-impregnated encapsulant material (figure 1).

The analysis results with the complex source model are more accurate, but creating this model relies heavily on the ability of the designer to determine the internal dimensions and emission parameters of the LED, which are typically closely guarded by the LED manufacturer. For this example the simplified LED model was used.

Backlight structure

Once the LED is modeled, the designer must make some tough deci-

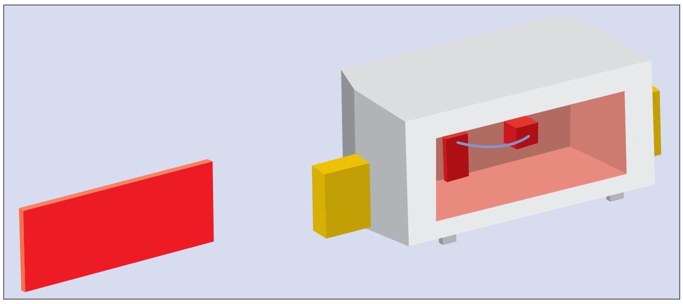

Fig. 1. A simple source model comprising a planar, rectangular emitting surface (left) and a complex source model in 3D (right).

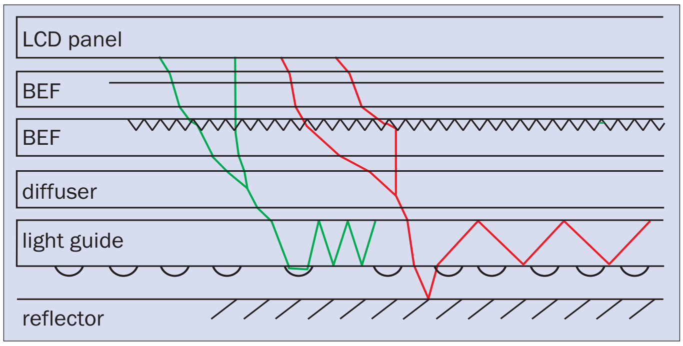

Fig. 2. Backlight stack (not scale). BEF: brightness-enhancing film.

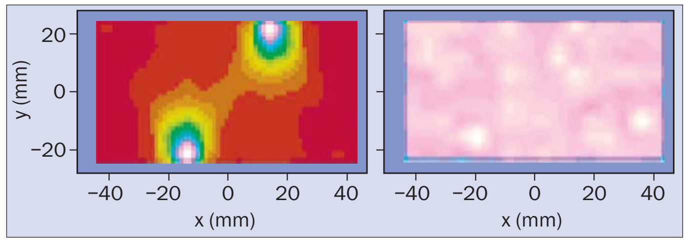

Fig. 3. Luminance distribution from the backlight, both before and after optimization.

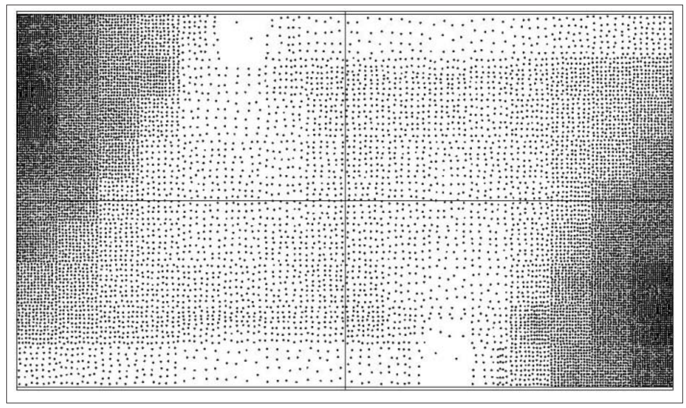

Fig. 4. The resulting extraction-feature pattern.

sions about the other components of the backlight. Backlights are designed as a stack. The layers of the stack represent physical elements, such as the light guide, diffusers, films and the LCD panel. To get good spatial uniformity into the LCD, the layers before the panel usually contain the light guide and some combination of diffusers and brightness-enhancing films (BEFs). The bottom layer of the system is a reflective surface that captures the light that leaves the light guide in the wrong direction and redirects it towards the LCD panel.

Even if the bottom layer is diffuse, another diffuser is often added between the light guide and the LCD panel to homogenize the luminance distribution further. It is also important to capture the light that leaks out of the thin edges of the light guide. Just below the LCD panel is the BEF layer. BEFs are typically thin sheets of plastic with linear microstructures. The linearity of the features increases the luminance in only one direction, so a crossed pair of BEFs is often used.

The LCD panel operates by extinguishing a particular polarization state of light, so it's often advantageous, from an efficiency standpoint, to tailor the polarization of the light favorably before it enters the LCD. To achieve this, polarization layers can be added to the stack or polarizing BEF sheets can be used. This example used a pair of crossed BEFs, a diffuser and a specular reflector as the bottom layer (figure 2).

Software modelling

A software package must be able to model all of these elements accurately. The bottom layer, independent of the reflectance profile complexity, must be accurately modeled. Simple reflectance models will be perfectly specular, near specular, perfectly diffuse or a combination of them all. A complex model will include measured data that take into account effects that can occur in a physical reflector, such as anisotropy and spectral response.

The model for any diffuser in the stack would have simple and complex variants similar in specification to the reflective layer, only its transmission curve is modeled. Some software packages offer simple models for the BEFs, and an accurate model would include the physical geometry of the microstructures. A software package must also be able to correctly model the polarization state of the light as it propagates through the stack, especially when polarizing elements are used.

Light guide design

The next step in the process is to design the light guide. Due to the favorably small nature of the chosen LEDs, the light guide will have a constant 1 mm thickness. Taper could be added to the light guide, which is an easy way to increase uniformity. However, with the layout of the LEDs in this example, tapering would be difficult.

Next, the shape and size of the extraction features must be determined. These parameters are usually dictated by the manufacturing process. Small hemispheres, prisms and pretty much any other shape that can be imagined have been tried as features. Software should not restrict the designer to a particular shape. They should be able to use ideal shapes in the initial design, and later switch to the true shape that the manufacturing process creates when the most accurate results are needed. The size of the feature determines whether the software is capable of accurate analysis. If the size is small compared with the wavelength of light, then conventional raytracing theory breaks down. In this case the interactions of the electric and magnetic fields of the light must be modeled, which requires special software and significant computer resources.

Light extraction

The last piece of this design puzzle is the extraction-feature pattern design. Herein lies the art of backlight design. Software can allow the designer to specify the location, orientation and size of each texture and model the design's performance. For light guides with millions of textures, this process is painfully tedious. Many software packages simplify this specification by allowing the designer to place, size and orientate features using simple fitting functions, the parameters of which can be optimized.

Optimization algorithms generally converge faster by choosing fitting functions that minimize the number of variables, but, especially with asymmetric patterns, the fitting functions still require numerous variables. By using an illumination optimization algorithm specifically designed for backlights, a designer can avoid having to use a fitting function, and radically faster convergence can be obtained.

This example started with 10 μm radius hemispherical bumps in an evenly spaced grid pattern and achieved good uniformity after only sixillumination simulations (figures 3 and 4).

Another important consideration for the pattern design is its regularity. Patterns that have large regions of linearity are likely to induce Moiré fringes because of interactions with the structure in the BEFs and in the LCD panel. To mitigate this, a designer can slightly randomize the placement of individual features. Some software applications support the automatic randomization (dithering) of pattern features by various amounts that can be specified by the user.

Conclusions

LEDs are starting to find their way into the LCD market as backlight luminaires. While this move holds many electrical and mechanical advantages to the system as a whole, it places an extra burden on the optical designer to produce efficient and uniform LCD illumination. Modern illumination design software can analyze the performance of the backlight system and, with the integration of optimization algorithms into the illumination software, the design process for the potentially irregular extraction-feature pattern becomes significantly easier.

Recently, special optimizers have been developed to make these backlight designs even easier. As this example shows, optimization coupled with a feature-rich illumination design software can provide a powerful tool for creating the best, brightest displays on the market.

About the author

Michael Zollers (mikez@opticalres.com) is an optical engineer with Optical Research Associates (www.opticalres.com).

In our December issue:

An update on LED industry standards, a review of OLEDs in lighting, reports from LEDs 2006, electronics and the automotive lighting conference, and much more...

Solid-State Lighting and LED News from the Photonics Cluster (UK)

LEDs Magazine is pleased to unveil a new feature in conjunction with Photonics Cluster (UK), a business network dedicated to supporting the photonics industry in the UK. Each issue we will report on PC(UK)'s activities in the LED field and cover the latest news from PC(UK) members. Cabot Media Ltd, publisher of *LEDs Magazine*, is a strategic partner of PC(UK).

News from PC(UK) members

PC(UK) members are encouraged to send news articles, case-studies and new product releases to the PC(UK) team at info@photonicscluster-uk.org for inclusion in this feature.

Radiant Research has introduced iDrive and iDrive-Lite, a new class of ultra-performance LED drivers optimized for multicolored LED lighting fixtures. The new systems are compatible with a wide range of leading high-power LEDs and were developed in partnership with leading LED fixture manufactures. The result is a versatile LED driver that requires no DIP switch settings and offers a range of new, simple-to-use functions to cut installation times for LED lighting projects dramatically.

- More details: www.ledsmagazine.com/press/13505.

Advanced LEDs Ltd and **Whiteley Electronics**, both manufacturers of outdoor LED lighting fixtures, are featured in our street-lighting article on p11 of this issue.

Marl has installed hundreds of highly ruggedized emergency LED lights in railway passenger carriages. The fixtures comprise high-intensity white LEDs that supply a defined pool of light in close proximity to doors and windows. They provide illumination for a minimum period of 90 min following an emergency.

- More details: www.ledsmagazine.com/press/13600.

Pro-Lite Technology says that its US partner, Labsphere, has expanded its line of SLMS LED systems. The SLMS LED xx51 series of LED test and measurement systems feature Labsphere's new CDS 510 CCD spectrometer and LS LED sockets for spectral results from 350–1050 nm in milliseconds. The additions of the CDS 510 and the LS LED sockets are part of Labsphere's drive to reduce the time that it takes to test and characterize LEDs accurately.

- More details: www.ledsmagazine.com/press/13392.

euroLED 2007

The LED and OLED lighting industry unite to drive forward the international euroLED 2007 Solid-State Lighting Conference and Exhibition in Birmingham, UK, on June 5–7, 2007. Already a highlight in the solid-state lighting calendar, euroLED 2007 offers a unique opportunity for organizations to penetrate, expand and understand the European and global LED and solid-state lighting markets.

Now in its fourth year, Europe's largest conference and exhibition dedicated to LEDs and solid-state lighting continues to generate unprecedented industry participation, securing support from leading organizations, including Future Lighting Solutions, Marl International, Osram Opto Semiconductors, Radiant Research, Supertex and TridonicAtco.

Due to exhibitor demand and increased visitor participation, the 2007 exhibition floor space will be increased by 100% and will feature over 50 international organizations. The two exhibition halls will provide an opportunity for companies to engage, promote and discuss LED and OLED lighting technologies with conference delegates and exhibition visitors in a single, convenient location.

There are opportunities for companies to participate at euroLED 2007 as exhibitors and industry sponsors. Although the call for presentation papers is now closed, there are still a few reserve presentation places available. For more details, contact Nina Blackmore, conference director (tel: +44 (0)121 260 6333).

- More details: www.euroled.org.

Upcoming PC(UK) SSL activities

Please call +44(0)121 260 6020 for more details of these courses to be held at PC(UK)'s facilities in Birmingham, UK:

- LED Practical Light and Colour Measurement Course: November 22, 2006.
- LED Product Safety Course: November 23, 2006.
- Introduction to LEDs for Lighting: December 7, 2006.

New PC(UK) SSL members

PC(UK) is delighted to welcome the following new members in the field of solid-state lighting:

Logic Procurement Asia: Logic provides its customers with leading-edge lighting control technologies and is focused on high-power LED and HID lighting control and driver systems.

OceanLED: OceanLED researches and develops all types of LED lighting for the marine, military and architectural markets. The company's poducts are all designed and produced in house.