LEDs MAGAZINE

Technology and applications of light emitting diodes

Issue 11 February 2007

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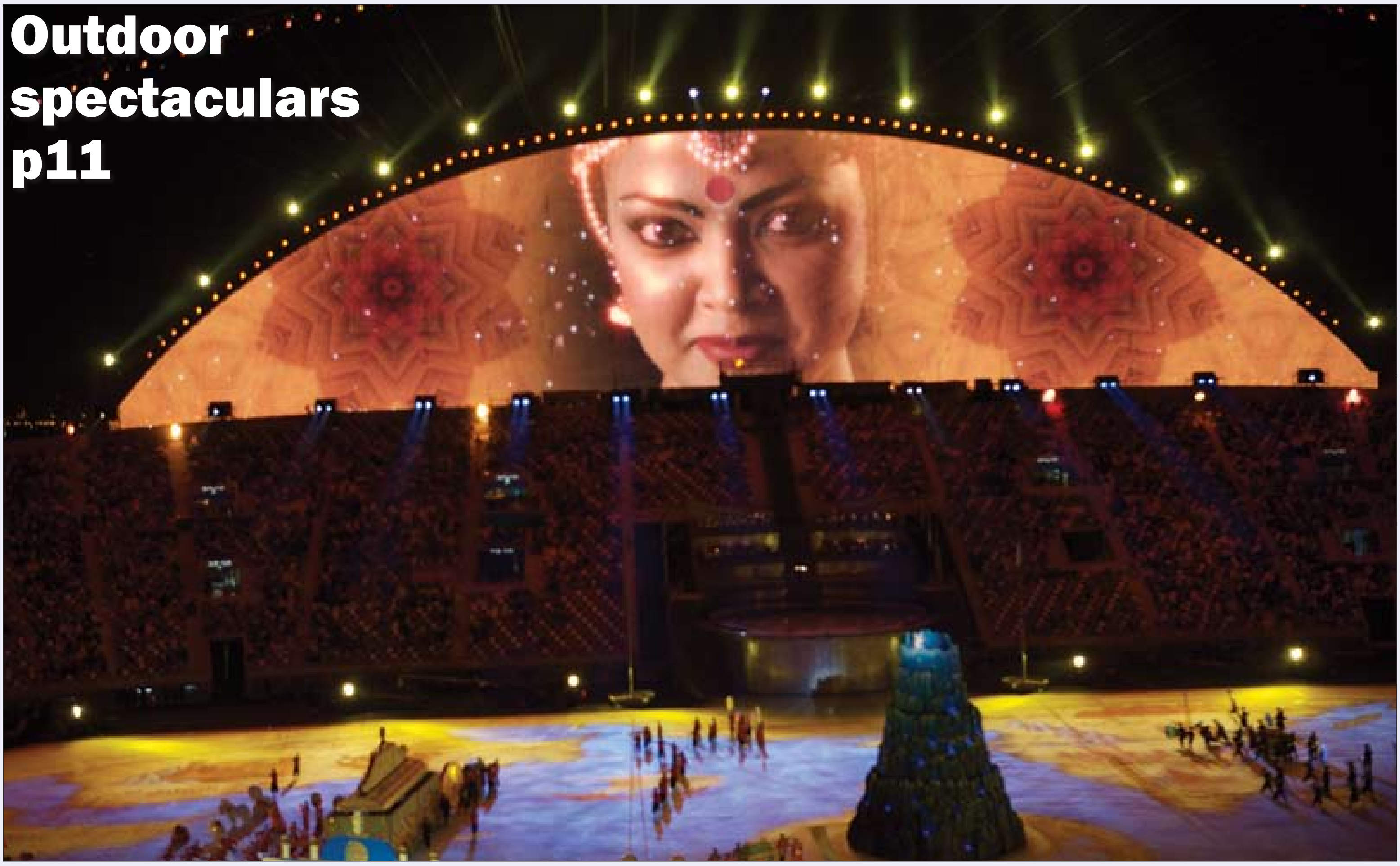

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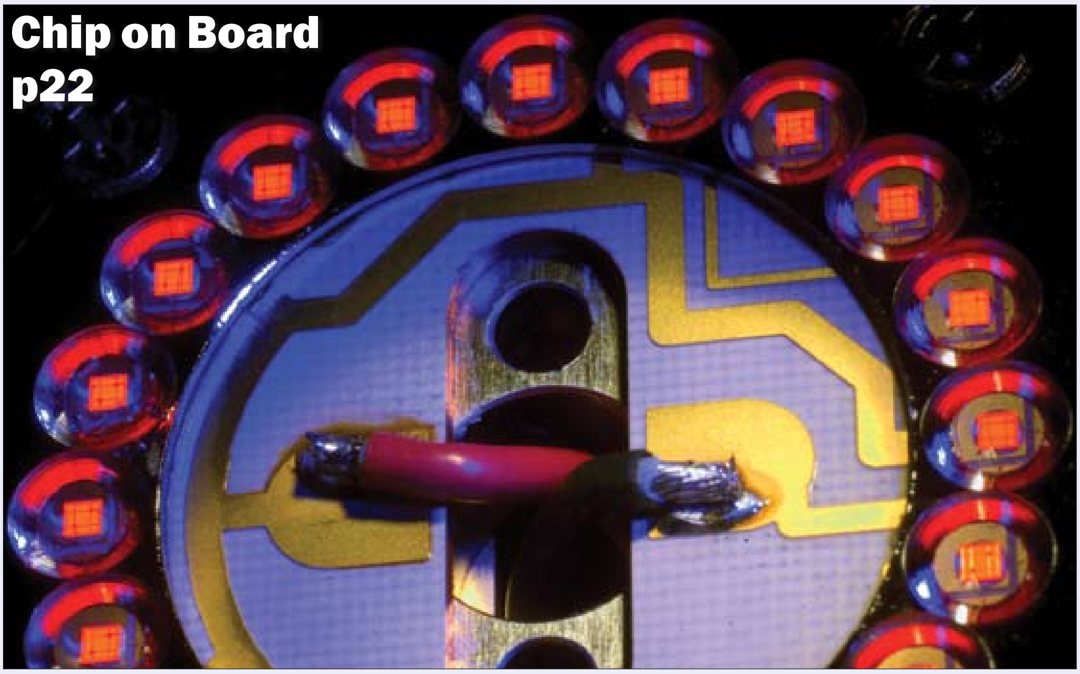

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LEDs MAGAZINE

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***LEDs Magazine* is published by Cabot Media Ltd**
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Print subscriptions
LEDs Magazine is available by paid subscription. Price includes 6 print issues per year plus the annual *LED Suppliers Directory*.
UK addresses £21.
Overseas £28 / $55 / €42.
Airmail £49 / $95 / €80.
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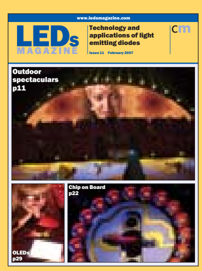


On the cover: Images courtesy of Element Labs (top), Philips (lower left), PerkinElmer (lower right)

POWER LEDS

Lumileds reports 115 lm/W and 136 lm from white LEDs at 350 mA

Philips Lumileds has claimed new performance records for high-power white LEDs with efficacies well in excess of 100 lm/W. The company expects that the enabling technologies behind these laboratory demonstrations will make their way into new and existing products, beginning in the current quarter.

While other companies have announced results above the 100 lm/W threshold, these have all related to small devices driven at 20 mA. For example, Nichia recently announced a 150 lm/W lamp-type white LED demonstration (see p17). The Lumileds announcement shows that developments in the power LED segment are keeping pace with standard LEDs.

The white LEDs developed by Lumileds' Advanced Labs are built around 1×1 mm^2 chips. The devices delivered 136 lm when driven with a current of 350 mA, corresponding to an efficacy of 115 lm/W. Lumileds emphasizes the correlated color temperature (CCT) of 4685 K, which is significantly lower than values typically reported. Equally impressively, at 2000 mA the white LEDs delivered 502 lm, corresponding to an efficacy of 61 lm/W.

Lumileds says that it achieved these record results for white LEDs by combining several new and innovative technologies, including breakthroughs in epitaxy, device physics, phosphors and packaging technologies.

Steve Landau, Lumileds' worldwide marcom manager, says that it will be a while before LEDs with this type of performance are available in the market. "However, it is clear that we have demonstrated a set of innovations that will enable performance to be significantly increased in the not too distant future," says Landau. "We will be releasing new products this quarter that will begin incorporating one or more of the technologies that went into the devices with the record performance."

CHIP TECHNOLOGY

Nonpolar and semipolar GaN LEDs show great improvement

Record performance figures for nonpolar and semipolar LEDs have been reported by researchers at the Solid State Lighting & Display Center (SSLDC) at UC Santa Barbara (UCSB), and the Japan Science & Technology Agency's Exploratory Research for Advanced Technology program (JST ERATO). Steve DenBaars, part of the UCSB team that also includes Shuji Nakamura, James Speck and Umesh Mishra, says that the team believes this to be "one of the biggest fundamental breakthrough in GaN emitters in several years".

Nonpolar and semipolar LEDs are a new class of gallium nitride (GaN) devices based on non-standard GaN material orientations. Compared with conventional GaN-based LEDs, the nonpolar and semipolar versions are expected to exhibit higher external quantum efficiency (EQE) at high current densities, as well as emitting polarized light. The new nonpolar LEDs have an external quantum efficiency (EQE) of 41% and radiant powers as high as 25 mW for standard size (300×300 µm) and operating current (20 mA). Semipolar LEDs of the same size exhibited EQE of 30% and radiant powers as high as 18 mW, also at 20 mA.

"The wavelength range is 400–415 nm now, but we will be making longer wavelength LEDs shortly," says DenBaars. "The long-term goal is higher EQE at higher current densities and longer wavelengths."

The UCSB groups have also reported conventional c-plane LEDs with EQE of 66% and 35 mW radiant power. These LEDs have been used to make white LED lamps with 116 lm/W luminous. While high efficiency is desirable in many applications, the polarized emission is also likely to prove important. "The nearest term application [for these devices] is LCD backlighting using polarized light from non-polar LEDs," says DenBaars.

● For more details, including a brief tutorial on nonpolar and semi-polar LEDs, see www.ledsmagazine.com/articles/news/3/12/16

DISPLAYS

Barco supplies miles of LED tiles for 2007 Detroit Auto Show

Auto manufacturers at the 2007 North American International Auto Show (NAIAS) in Detroit used large numbers of LED tiles from Barco (see photo, showing the Pontiac booth) and other suppliers. LEDs were designed into walls and ceilings, and were created with complex curves and sweeping arcs of video imagery. See www.ledsmagazine.com/articles/news/4/1/19 for more details. There were also some cars on display, as described in our article on page 24.

LED MANUFACTURING

Lower LED shipments pull Cree revenue downwards

Cree's LED revenue for the quarter ended 24 December 2006 was \$65.5 million, down 21% compared with the previous quarter and down 24% year-on-year. Overall, LED unit shipments fell by 15% sequentially, but were still 5% higher than the same quarter last year. However, the company's average selling price (ASP) for LEDs was down 7% sequentially and down 28% year-on-year.

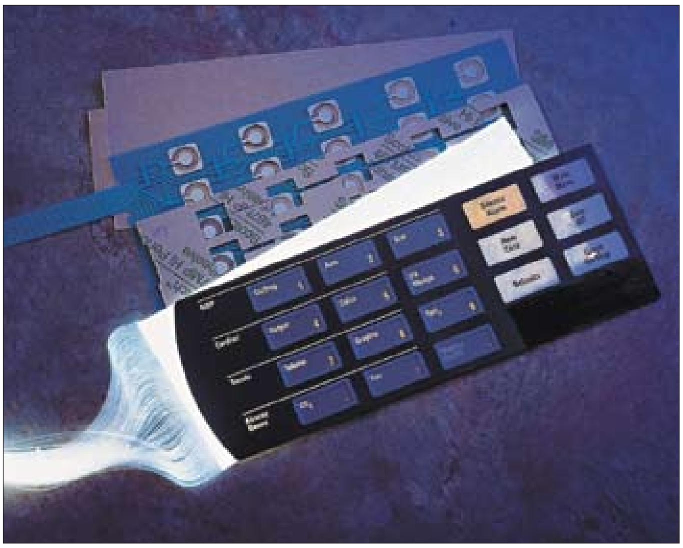
Chuck Swoboda, Cree chairman and CEO, said that LED component sales (such as XLamp packaged LEDs) increased to more than 10% of total LED revenue for the first time. "This growth is an important leading indicator of how we plan to grow the company over the next several years," he said.

LED production cost per unit increased 10% sequentially and 3% year-on-year, reflecting a shift from mid-brightness to high-brightness LEDs (Cree's own classifications), with the latter now accounting for 48% of production.

Cree also said that it had qualified the first processes for the growth of LEDs on four-inch wafers, which will eventually help the company to improve the productivity of large-area LED chips.

ON OUR WEBSITE

Fiber optic technology delivers versatile LED-based illumination



Fiber optic technology has developed to make the most out of the brightest LEDs, spreading their light efficiently and flexibly, while minimizing power, circuitry and LED count. Fiber-optic backlighting, in particular, is an increasingly popular way to differentiate product designs with light, increasing clearly perceived customer value. Fiber-optic panels couple with LEDs to provide more flexible, adaptable and cost-effective alternatives to such common technologies as molded plastic light pipes, EL, LED arrays, discrete (embedded) LEDs and CCFLs.

- Read this article authored by Lumitex Inc on our website at www.ledsmagazine.com/articles/features/4/1/2

LICENSING

Lamina and Neo-Neon sign deals with Color Kinetics

Color Kinetics has signed two new licensing agreements, one with Lamina Ceramics, a manufacturer of LED light engines based in Westhampton, NJ. The deal will allow Lamina to offer licensed products incorporating digital intelligence, for example additive color mixing through DMX control. Lamina customers who develop fixtures based on the CK-licensed components will be covered under Lamina's license as well.

The other new licensee is lighting manufacturer Neo-Neon, based in Guangdong Province, China. The terms of the licensing agreement reflect that some of Neo-Neon's products resemble those developed by CK. "The agreement provides a measure of protection for our Lighting Systems business by requiring a special royalty rate on sales of products that resemble our own," said Bill Sims, CK's president and CEO.

Two weeks before the deal's announcement, Color Kinetics filed a patent infringement lawsuit against Neo-Neon. The lawsuit was subsequently dismissed before the deal was announced. However, in a letter to *LEDs Magazine*, Neo-Neon said there was no link between the lawsuit and the licensing deal.

- More details: www.ledsmagazine.com/articles/news/4/1/3

LINEAR LED LIGHTING

LED Linear unveils 2500 lm linear lighting module

LED Linear has unveiled a flexible power LED module with an output of 2500 lm, or 625 lm/meter. The VarioLED Flex SOL also provides a luminous flux of 1900 lm in the warm-white version. Based on flexible printed circuit (FPC) technology, the 4 m long modules contain 144 half-watt LEDs, and are only 3 mm thick. The German manufacturer achieved very high efficiency with simultaneously extreme lifetime via a superior thermal design.

- More details: www.ledsmagazine.com/press/14813
- LED Linear: www.led-linear.com (see also p18).

STANDARDS

UL initiates safety certification for LEDs and fixtures

Underwriters Laboratories Inc. (UL), a product safety certification organization, is developing a set of requirements specifically for solid-state lighting. The purpose, says UL's Eli Puszkar, is to ensure that this new technology enjoys the same level of acceptance and consumer confidence as other lighting technologies.

LED manufacturers need to consider risk of shock, risk of fire and biological hazards such as retinal damage when designing their products. LEDs supplied by a Class 2 supply do not present a shock hazard due to the voltage and current limitation, while those that are either line-connected or otherwise connected to a non-Class 2 supply will need to comply with standard insulation and accessibility requirements.

In terms of fire risk, the temperature rise exhibited by LED systems might bring them close to the limit of 90 °C, the maximum permitted by the building code in the US on combustible surfaces. UL says that LED luminaire designs should take this into account and must undergo temperature testing to ensure all components within the luminaire and the outside surfaces are operating within their specified temperature ratings.

Early in 2007, UL will officially publish UL 8750 titled "Outline of Investigation (OOI) for LED Light Sources for Use in Lighting Products". When released, this OOI will be used as the main document within UL for all investigations of the LED light sources used in UL Listed lighting products. The assembled device will still be evaluated for Listing to the appropriate end-product standard. For example, the LED light source in an LED luminaire will be evaluated according to the OOI, while the LED luminaire itself, as a complete product, will be evaluated according to the Safety Standard for Luminaires, UL 1598.

Also, during the first quarter of 2007, UL will form, with the support of the LED industry, a balanced Standards Technical Panel (STP). The panel will work on drafting and publishing an ANSI Compliant

LED standard (using the OOI as a starting document) for products designed for sale in North America. People interested in participating in the standards process can contact UL at leds@us.ul.com.

- UL website: www.ul.com/lighting/ledsummit
- The full-length version of this article can be viewed on our website at: www.ledsmagazine.com/articles/features/4/1/3

LUMINAIRES

LED luminaires fall short in initial round of testing by DOE

LED luminaires have faired poorly in a pilot round of testing conducted within the US DOE's Solid State Lighting (SSL) program. As part of the Commercial Product Testing Program (CPTP), testing was carried out by various laboratories on four LED luminaires, selected to represent a range of applications, designs and manufacturers.

The CPTP report shows that the efficacy of tested LED luminaires was significantly lower than the efficacy values of the LEDs used. The report expresses concern that, at this early stage in the development of the SSL market, product performance data should not be used misleadingly.

The testing labs followed test procedures specified in LM-79 draft 2 (IESNA Guide for Electrical and Photometric Measurement of Solid-State Lighting Products). Results are shown in the table.

Many datasheets for LED luminaires state the luminous efficacy of the LEDs contained within. For the tested luminaires, these values were in the range of 36–55 lm/W. However, testing showed that the luminaire efficacy was significantly lower, in the range of 11.6–19.3 lm/W.

The DOE concludes that it is inappropriate to suggest that a high LED efficacy (lamp efficacy) indicates that a luminaire using those LEDs has high efficacy. This result comes as no surprise to those familiar with working with LEDs, but it represents an important lesson for the lighting industry as a whole. Traditionally, when using incandescent or fluorescent light sources, lamp efficacy provides a good measure of the luminaire performance. However, with LEDs,

Commercial LED luminaire test results

	LED efficacy (lm/W)*	luminaire output (lm)	luminaire efficacy (lm/W)	CCT (K)	CRI
CPTP 06-01 Downlight	40	193	12.8	3012	70
CPTP 06-02 Under-cabinet light	55	166	16.1	**	**
CPTP 06-03 Downlight	45	298	19.3	2724	67.3
CPTP 06-04 Task light	36	114	11.6	**	**

Partial results from the CPTP study. (*) Data published by LED manufacturers. (**) Test procedures do not provide guidance on obtaining color metrics for SSL luminaires that are not suited to testing in an integrated sphere with spectroradiometer.

the use of traditional lighting performance metrics (primarily based on lamp efficacy) could be misleading if used to compare light output or energy efficiency of an SSL product with a product using another light source.

The CPTP report says that measures of LED efficacy can be useful to evaluate the performance of available components. However, it adds: "These data should not be used in product literature for luminaires to convey an indication of the performance of the luminaire at this time."

Looking at the results in the table, the LED downlights delivered less light than incandescent or fluorescent alternatives, while the efficacy of the LED luminaire falls between comparable incandescent and fluorescent values. Similar results were seen for the under-cabinet light. In the task lighting category, further work is required to evaluate the directional characteristics of the LED products.

Industry groups, standards organizations and the DOE are working quickly to fill the voids in product standards and testing procedures for SSL technologies, says the CPTP report. However, in the meantime, players in the field of SSL technology have a duty to protect the potential of SSL by ensuring that performance claims are accurate, representing the entire luminaire, and do not mislead buyers and possibly cause long-term damage to the SSL market.

Further testing is planned within the CPTP to gain a clearer understanding of how to assess the performance of SSL products compared with traditional lighting sources, to identify how different testing procedures may affect results, and to clarify how traditional photometric practices apply or do not apply to SSL products.

● CPTP: www.netl.doe.gov/ssl/comm_testing.htm

STANDARDS

DOE releases draft Energy Star requirements for SSL luminaires

As part of its strategy to accelerate market introduction of solid-state lighting, the US Department of Energy (DOE) is extending its Energy Star program to LED-based luminaries. The draft document describes how products targeting the general illumination market will be able to comply with program requirements. Energy Star is a voluntary labeling program designed to identify and promote energy-efficient products.

The document specifies numerous requirements. For example, there are eight designated correlated color temperature (CCT) values, and the LEDs must have a useful life of 35 000 hours based on an average rated lumen maintenance of at least 70% of initial device lumens. There are definitions of color spatial uniformity and color maintenance over lifetime, as well as driver requirements, packaging requirements, and warranty requirements for luminaires.

Application requirements are also defined for specific types of luminaires. For under-cabinet kitchen lighting, the luminaire should deliver at least 150 lm per linear foot, with no more than 75% of total lumens within the 0–60° zone. The minimum luminaire efficacy and CRI are 23 lm/W and 80, respectively.

The draft document will be discussed at a stakeholder workshop in early February.

● DOE website: www.netl.doe.gov/ssl/energy_star.html

Giant architectural and entertainment projects showcase LED capabilities

Several recent projects have underscored the incredible effects that can be achieved with color-changing LEDs on large-scale architectural and entertainment projects, blurring the boundaries between displays and lighting.

Two of the projects were built in Doha, Qatar, for the 15th Asian Games held during December 2006. Inside the stadium, Element Labs built a giant, curved LED screen, the largest ever custom-built for a large event. The entire 77 mm pitch LED screen is 165 meters wide along the curve, reaching 39 meters at its highest point. The screen comprises 20 000 individual Versa RAY fixtures, containing a total of 762 000 individual LEDs. The linear fixtures have RGB LEDs positioned every 77 mm, and if laid end to end would span 58 km (over 36 miles).

● More details: www.ledsmagazine.com/articles/news/4/1/21

Aspire Tower, Doha, Qatar: The 12 m Olympic flame for the Asian Games was held at the top of the 300 m Aspire Tower, which is covered with a unique lighting skin designed by Kevan Shaw Lighting Design (KSLD). The skin consists of a grid of nearly 4000 three-color LED luminaries individually addressed to allow animated patterns to be played across the tower's skin. The luminaries, supplied by Solar GB, contain six 1 W Luxeon LEDs that are driven normally at 350 mA but also have the ability to pulse at a higher output to create the strobe sparkle effect required by KSLD.

● More details: www.ledsmagazine.com/articles/features/4/1/1

Dexia Tower, Brussels: Visitors to Brussels over the New Year period were able to define colors and patterns displayed by LED lighting fixtures that transformed the Dexia Tower into a giant interactive LED display. The 145 m high building contains 4200 windows that are each fitted with individually controlled RGB LED bars, supplied by Space Cannon. LAb[au], a Belgian digital design and art lab, installed an interactive station where visitors could define the colors and shapes displayed on the LED screen via a multi-touch screen.

● More details: ledsmagazine.com/articles/features/4/1/4

The Place, Beijing: A huge new LED skyscreen forms the centerpiece of The Place, a new retail development in Beijing's central business district. The display is 250 m long and 30 m wide, and is suspended six stories high (80 feet) above a plaza between two new retail centers. The concept was designed by Jeremy Railton, president of Entertainment Design Corporation, who was the original designer of the Fremont Street Experience in Las Vegas, the world's largest LED screen. The displays at The Place were supplied by Taiwan-based LED display manufacturer Opto Tech.

● More details: ledsmagazine.com/articles/features/4/1/5

ELEMENT LABS

An LED screen dominates the Doha Asian Games stadium.

JEREMY RAILTON

The LED skyscreen attracts shoppers to The Place, Beijing.

©KEVAN SHAW LIGHTING DESIGN

Olympic flame atop the Aspire Tower in Doha.

LAb[au]

The Dexia Tower in Brussels, with the interactive station at its base.

From fossil fuels to solid state for household lighting: a 'small' solution for a large problem

Light Up The World Foundation has been at the forefront of efforts to bring LED lighting to the developing world for several years. *LEDs Magazine* spoke with LUTW founders Dave Irvine-Halliday and Ken Robertson to get an update on the foundation's activities.

Testing lamps bound for Sri Lanka in Light Up The World's lighting lab.

A girl in Nepal enjoys the benefits of reading under white solid-state illumination.

LUTW's Dave Irvine-Halliday (center) assembles systems in India.

What was the purpose of LUTW when first conceived?

Light Up The World Foundation (www.lutw.org) is an international humanitarian organization dedicated to illuminating the lives of the world's poor. It is the first organization to utilize solid-state lighting technologies powered by renewable energy to bring affordable, safe, healthy, efficient and environmentally responsible lighting to people currently without access to proper lighting. LUTW is the world's leader in the advancement and diffusion of this technology for development purposes and remains globally active in setting standards in this field. LUTW systems have been in the field since 1999 and, to date, LUTW has installed 20,000 lighting systems in 42 countries.

LUTW's genius was in the introduction of an economically viable lighting system that could displace kerosene without the financial support of subsidies. "Bottom of the pyramid" families pay $25–$150 annually for kerosene. Women can trek for days to the nearest kerosene depot and children suffer from the debilitating effects of smoke-filled rooms. The lack of affordable lighting is connected to the cycle of illiteracy and poverty. LUTW lighting systems, in many cases, have a payback of less than one year when micro or merchant credit is extended.

International development institutions from development banks to GTZ now recognize the potential of small-scale, highly efficient and long-lasting solid-state lighting systems as filling a very real need for families living at the bottom of the economic pyramid. LUTW has provided the leadership in proving out and educating these institutions on the importance of adopting and adapting solid-state lighting as a replacement for kerosene. LUTW has set the technical standards and lit the way for the lighting of this century.

How has LUTW's scope expanded in the intervening years?

LUTW has grown from a single idea into a highly professional, globally active humanitarian organization with important links in industry, academia and civil society. The organization has increased its capacity and surpassed expectation through building strong relationships between local communities, businesses, universities and NGOs. The foundation has worked with more than 50 partners including Stanford University, MIT, Harvard and Cornell. LUTW has also partnered with "best in class" NGOs including the World Wildlife Fund, the African Wildlife Federation, Green Empowerment, World Vision and CIDA. LUTW's innovative methods to bring affordable, safe, healthy and reliable lighting to the poor through enterprise development, has won international acclaim and prestigious awards, for example from Rolex, Tech Museum and Saatchi & Saatchi.

Through generous support from interested individuals, corporations, host country organizations, international foundations and industrial partners, Light Up The World Foundation has lit up thousands of homes, schools, orphanages, community centres and clinics in 42 countries throughout the developing world. More than 100 000 people have been impacted directly by this new and innovative approach to development. LUTW's goal of reaching the approximately 2 billion people worldwide without access to adequate lighting is ongoing. Through replicating efforts in enterprise development and the extension of credit, LUTW has also set standards in harnessing the force of the market in achieving the aims of international development.

What problems have been solved with white LED lighting?
LUTW projects have brought tangible social, environmental and economic gains to communities by enhancing their health and safety, fostering local education, helping to develop an economic infrastructure, and protecting the physical environment. LUTW technology works to break the entrenched cycle of poverty by providing vastly improved levels of lighting in homes. Among the many benefits, home-based industry and evening study are facilitated.

- **Health & safety** The consequences of fuel-based lighting are seriously debilitating to the developing world. Kerosene, a primary lighting fuel, causes heavy air pollution which can result in illnesses and death. Kerosene and candles are also responsible for countless fire catastrophes. LUTW's safe, reliable and near-permanent WLED lighting reduces air pollution in the home, enhancing safety (especially for old people) and improving health conditions. Each village where kerosene lamps were replaced with LUTW systems has reported significant improvements in health.
- **Local business opportunities** Local enterprise development is a fundamental component of LUTW's philosophy. Conventional project delivery combined with a local business start-up meets the twin demands of reaching a very poor segment of the population while simultaneously reinforcing entrepreneurship as one of the most effective and sustainable forms of local development. Through this approach LUTW ensures that installation, maintenance and support services continue to replicate after the initial projects have seeded the technology. LUTW does not seek to own local companies but will assist in their startup, development of expertise and sustainability.
- **Economic development and poverty reduction** Kerosene and other non-electric light sources used in developing countries are expensive and inefficient. Consider this: a poor rural family in the developing world pays the equivalent of what a family from North America pays for lighting services, but they receive less than 0.2% of the light (lumen-hours). LUTW provides systems at a special price negotiated with the component suppliers. The long life of WLEDs and low power requirements result in extremely low ongoing maintenance costs. Cumulative savings from kerosene-replacement significantly bolsters disposable incomes and thus contribute significantly to poverty reduction at a household level. Lighting also facilitates the establishment of indoor and evening cottage industries, helping people to earn more income.
- **Education and literacy** Light from kerosene lamps is poor and inefficient, and poor lighting affects literacy and education. The light from kerosene lamps is so poor that children can only see their schoolbooks if they are almost on top of the flame, directly inhaling the toxic smoke. Heat fracture and spillage is common and results in countless injuries to children. WLED lighting allows children to study after sunset in a safe, healthy and bright environment.
- **Environmental savings** Dry-cell batteries contribute a significant amount of toxic heavy metals to the local environment. LUTW's ultra-efficient WLEDs run off rechargeable sealed batteries that last much longer and result in fewer battery disposals. The installation of WLEDs also reduces the demand for firewood, thus mitigating deforestation and desertification. LUTW's WLED replacement bulbs for flashlights increase the battery life by at least a factor of 10.

• **Greenhouse gas emission reductions** WLED lighting powered by renewable energy replaces fuel-based lighting, thus reducing greenhouse gas emissions responsible for climate change. LUTW estimates that the replacement of kerosene lamps with WLED lighting saves approximately 100 kg of CO_2 per kerosene lamp annually.

What are the WLED system requirements?

We have set minimum performance standards for all the components in a home lighting system. In the case of WLEDs, 35 lm/W in light output and 30 000 hours of MTTF are the minimum acceptable levels. However, the performance of WLEDs that we use in present SSL systems is much higher than the above levels and we strive to deliver the best possible products. We have standardized our systems with a 5 Wp photovoltaic module along with a battery unit and charge regulation. This combination provides families with two days of operating autonomy.

Short-circuit protection and low voltage interrupt are among the essential components that LUTW has incorporated to ensure long battery life, low maintenance and safety. LUTW systems have continued to operate without need for battery replacement for more than five years. LUTW has now developed a suite of products that comprise an expandable home lighting platform. We purchase system components only from well recognized and dependable international companies.

Do the supplied systems conform to a set of technical specifications?

Yes. We continuously test and assess the equipment we use. All installations are monitored for their technical performance and improvements are incorporated into next-generation products. Since 1999 we have tested many classes and varieties of WLEDs. A disturbing trend is the use of low-quality diodes in many products now available. Unfortunately, many current solid-state lighting systems lack sophisticated battery management that is essential to dependable performance and long life. LUTW systems have become the platform by which small-scale solar home systems are now judged.

How does LUTW spend the donations it receives from, for example, Shuji Nakamura?

The vast majority of public donations go directly to implementing lighting projects since the full-time staff salaries come largely from donations from other foundations specifically intended to assist LUTW staff expand their capabilities. The donation from [UCSB professor] Shuji Nakamura was split 70% to the foundation's international projects and 30% towards the research work at the University of Calgary of Dave Irvine-Halliday.

How do you see LUTW evolving in the future?

LUTW is at a very exciting point in its development as an NGO. WLED technology improvements are providing increasingly higher quality and greater amounts of light, and these innovations are being implemented as affordable and useful products for developing world society. The foundation's dedication to monitoring the social impacts and development outcomes from its initiatives are beginning to attract significant interest from large NGOs worldwide. Spreading this unique development intervention through both charitable channels and the local marketplace is showing impressive results. •

Links

LUTW: www.lutw.org
Sustainability Channel: www.ledsmagazine.com/sustainability

Lighting market and global energy dilemma stimulate calls for an LED industry association

In the first of a series of columns for *LEDs Magazine*, **Jed Dorsheimer** of Canaccord Adams presents thoughts from the 2006 LED Leadership Summit, including a call for the formation of an LED industry alliance.

Recently, I was invited to attend the inaugural LED Leadership Summit in San Diego, California. The conference, the first of its kind, was organized by the "big five" LED manufacturers: Nichia, Cree, Philips Lumileds, Toyoda Gosei and Osram. The goal; to create a forum where LED companies, lighting companies, and regulatory and legislative bodies could come together at a senior level to start the first real LED industry association.

The message was simple: the LED industry has successfully penetrated several niche applications, the largest of which has been the mobile handset market. However, recent growth has slowed, as this market has saturated and competition has increased. At the same time, LED technology has dramatically improved and handset volumes have allowed prices to decline, opening up new market applications such as digital billboards and signs, LCD backlighting units (BLUs), automotive interior and forward headlights, and specialty lighting. While these markets are creating sustainable business models, the desire among many of the invited speakers was to disrupt the general illumination market.

Why? Because the market for general illumination is huge. The Freedonia Group, a leading market-research firm, estimates the lighting market is currently worth around $102 billion annually, and will grow to over $130 billion by 2011. When one takes into account the longer term inherent advantages of LEDs, as James Sweeney of Stanford University outlined during his talk, "real economic value" is created in the form of a multi-billion dollar annual market – a goal embraced by suppliers, customers, designers, institutional investors and venture capitalists.

Show me the lumens

The week after the LED Leadership Summit, I was also invited to present at the Controlling Lights conference in San Diego. Attendees included many representatives from traditional lighting and control companies such as Osram Sylvania, Philips, Lutron and Crestron, not to mention several lighting designers. Interestingly, the concerns voiced at the Controlling Lights conference were similar to James Benya's presentation at the Leadership Summit, challenging the LED community to "*Show Me the Lumens*", that sent a shiver of skepticism through attendees.

In my analyst role I can be close to a market but can also step back and view the market from an outsider's perspective. For those involved in the day-to-day activities of an emerging market, it is sometimes easy to succumb to the hype. In my opinion, this was precisely the message that Mr Benya was trying to stress – don't believe your own hype.

Perhaps some of the skepticism at the installer/designer level is attributable to the similar promises that compact fluorescent (CFL) technology offered over the past three decades. CFL is just now making headway in the market. Many attribute the disappointment of CFL to overly optimistic expectations supported by egregious claims and interoperability problems among manufacturers (primarily ballast-related), coupled with high initial costs for users to stomach.

Disrupting traditional markets

So why won't LEDs and therefore solid-state lighting (SSL) succumb to these same challenges? Will the SSL market take 30 years to disrupt the traditional lighting market? I hope not – on the other hand it could provide many years of interesting columns. Kidding aside, in comparing the CFL and LED technologies I do see some similarities. More importantly I see some very distinct differences, and thereby advantages, that may aid LEDs in disrupting the traditional lighting markets, which I categorize as incandescent, ceramic halogen, fluorescent and compact fluorescent, and high intensity discharge (HID).

First, LEDs are semiconductors and as such exhibit a technological roadmap that far exceeds the luminous efficacy of any traditional lighting technologies. In fact, the DOE estimates that by 2020 LED light sources will reach 200 lm/W, usurping even the most efficient HID lamp (i.e. low pressure sodium) at 130 lm/W. Nichia's President Ogawa-san, in a rare speaking appearance at the Leadership Summit, highlighted the benefits of LEDs and announced that Nichia has demonstrated 150 lm/W with a lamp-type LED driven at 20 mA.

Secondly, SSL has the opportunity to change the way we think about light. As a point-source emitter with specific spectral wavelengths, higher potential color rendering is possible. Moreover, LEDs have the ability to improve our lives – several studies have shown that the replication of a more natural light can help people heal faster, improve behavior, increase productivity – resulting in real economic value add.

Thirdly, the current momentum driving the movement towards SSL is unquestionably the highest the lighting industry has ever experienced, and enjoys global industrial and governmental support. Finally, subscribing to the Clayton Christensen school of thought, SSL is a paradigm shift in the way light is delivered to the end user – thus destroying the traditional razor/blade model and presenting an opportunity for disruption in the lighting market.

The global energy dilemma

The Leadership Summit offered a refreshingly high-level overview of the current issues facing the markets served by LEDs. Clearly the key message to emerge from this event was the energy crisis. From the US to China, whether an automotive OEM or the world's largest retailer, every speaker provided a perspective on the current energy issues facing our global society.

Chuck Swoboda, chairman and CEO of Cree, opened the conference by describing the current crisis facing the US. Demand for electricity in the US is expected to increase by 19% over the next ten years, but confirmed power capacity of an already constrained grid will only increase by 6% during the same period. This will cause severe problems in five major US areas in the next two to three years. With lighting consuming 22% of electricity in the US, he said, "LED technology is the obvious solution to improve the energy demand equation".

Supporting this view, Theo van Deursen, CEO of Philips Lighting, stated that switching to LEDs could lead to a reduction of 273 trillion tons of CO_2 emissions annually, equivalent to planting 13.6 billion trees. The economic saving would be roughly €51 billion per year.

Wu Ling, General Secretary of the China SSL Alliance, provided a perspective on China's interest in SSL. Not surprisingly, China being the second largest consumer of electricity in the world, it is looking to reduce its dependence on fossil fuels such as coal and oil. As Ms Ling illustrated, with roughly 69% of China's electricity being derived from coal versus 24.2% in the US and 27.2% in the world, reduction in electrical loads is critical to China's growth. Heavy coal usage in China already has serious side effects, such as acid rain in heavily populated areas. Ms Ling cited a fourfold increase in Chinese GDP by 2020 – clearly China must look to more sustainable energy options such as SSL, solar and hydroelectric power.

Call to action

I found Chuck Swoboda's "Call to Action" rather insightful. Government, he said, should recognize that LEDs can potentially save more energy in the short-term than can be generated by alternative technologies (wind, solar) combined. While I have not checked if this claim is actually true, the important point is that SSL is a key element in the move towards more sustainable energy solutions. Also, it's time for significant incentives to drive the use of energy-efficient lighting, an approach that has already worked in the traffic-signal market.

To lighting fixture companies, Swoboda said that the industry is changing and asked "Can you afford not to change?" These companies should stop waiting and invest in the engineering to design with LEDs, integrate them into fixtures and get new products into the market. Also, the industry needs fixture manufacturers to drive standards that leverage the benefits of LEDs technology to change old paradigms.

LED technology providers, meanwhile, should continue to increase lm/W and reduce costs. They should develop better products and bridge the gap between themselves and the fixture companies. And finally, they should build a real LED lighting trade-association that is capable of driving the key initiatives across the industry on a global basis.

An end user's perspective on sustainability

Perhaps the most interesting and encouraging presentation was that describing the continuing evolution of sustainable facilities at Wal-Mart, the world's largest retailer. To Wal-Mart, every-day low cost equals every-day low price. As the company's Charles Zimmermann explained, this means a retailer that has the lowest operating costs – with scale – can conceivably offer its customers the lowest prices and deliver the greatest value. Seems obvious, right? Apparently not, as Wal-Mart is one of the few companies that has invested more than $500 million to help develop and implement "green" technologies such as daylight harvesting, heat reclaim, centralized EMS/monitoring, active de-humidification and exterior LED signage in an effort to reduce its energy consumption. In fact, Wal-Mart even invites its competitors to its new store openings to educate them on the benefits of going "green".

When quizzed, few in the audience guessed that two-thirds of Wal-Mart's operating costs come from purchased electricity. Fuel and transportation, which most people associate with going "green", represented only 7% of the total, even though Wal-Mart has more than 15 000 trucks on the road each year driving more than 900 million miles.

The next evolution of Wal-Mart's "green" initiative is LED refrigeration lighting. All new stores will have this technology and Wal-Mart is beginning to retrofit existing stores. The company expects a 66% reduction in electricity consumption compared with incumbent fluorescent technology – see www.ledsmagazine.com/articles/news/3/11/16 for more details. After analyzing efficiency losses in its frozen-food sections, Wal-Mart decided to encase all of its refrigeration. Turning to the lighting, Wal-Mart found that LEDs excel where fluorescent fails; LED efficacy increases as the temperature decreases, and fluorescent lamps exhibit much lower lifetimes in cold conditions. Also, with LEDs the heat is removed from the back of the device, while fluorescent technology causes convective heating of the food, increasing the refrigeration load.

Finally, Zimmerman explained Wal-Mart's decision to "shut off its lights" by implementing occupancy sensors and LEDs dimming capabilities to turn off the lights when there are no customers around. This is a particularly important issue for a 24-hour retailer during the 1.00 a.m. to 4.00 a.m. timeframe. As a customer walks down an empty aisle, occupancy sensors will notice the movement and turn on the lights in the cases so the customer's experience is the same as if the lights were running prior to their arrival. A delayed timer will then turn off the LED lights after the customer has passed. Perhaps this will change the age-old question of whether the light really turns off in the refrigerator to whether the lights really turn off in a Wal-Mart store.

Concluding thoughts

As an invited attendee of the conference I found the benefits of having all of the key people involved in this industry in one place at the same time was significant – I thought about saying "priceless", but then next year's ticket prices would be even higher.

The more conferences I attend and present at, the more I hear the same comments. The first complaint I typically hear is: "LED manufacturers need to stop cherry-picking their best results and find a common testing platform by which results are measured." The second comment is: "Rapid advances in the technology are actually hurting adoption because as soon as we, the luminaire manufacturers, decide to commercialize the product, it is rendered obsolete by the next record-breaking lamp." And the third comment is: "Egregious claims are going to hurt our industry."

Perhaps I can shed some light – or at least my own opinion – on the previous comments. I too believed that many of the reported figures by many of the LED lamp manufacturers seemed inflated and overly optimistic, mainly due to huge driver and optical losses at the luminaire level. This is why I have started to perform independent benchmark analysis and have tested many of the LED lamps available today. What I have found is that many of the claims at the lamp level are actually accurate. I have measured many of the available LEDs on the market with the sole focus on power packages in RGB, warm white and cold white. What I am finding is a bifurcated market with several leading suppliers at the high end and just as many in the middle. Only a few are at what I would consider the low end of the market. (If you are a packaged LED manufacturer, or an LED chip manufacturer with access to your packager's lamps, and you desire independent validation of your product, you can email me at LEDBenchmarking@comcast.net). This means many of the claims at the lamp level are accurate – clearly more work is needed to improve the total system, though.

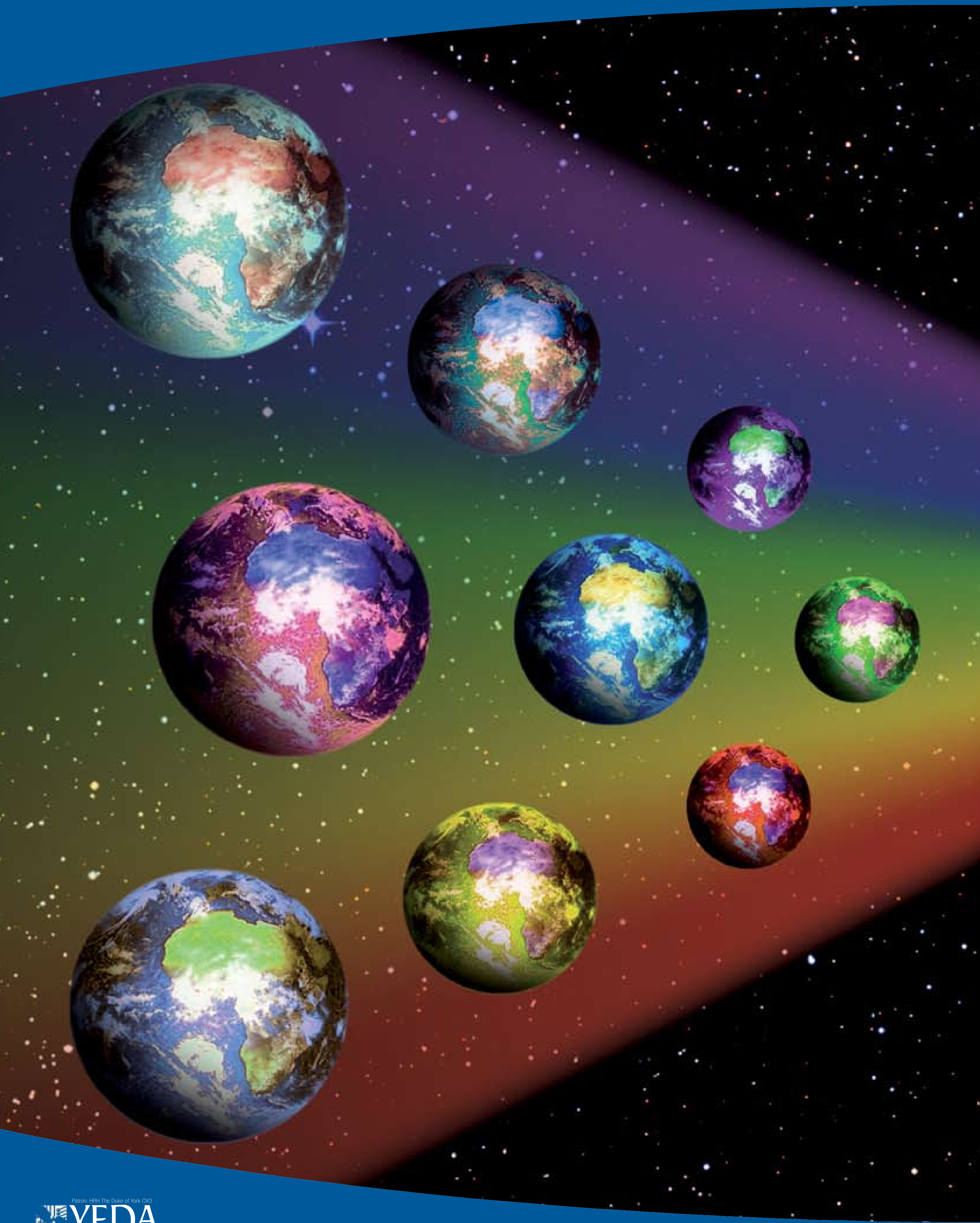
As for advances in LED technology limiting adoption, I disagree emphatically, although I agree that overly optimistic or irrelevant claims could limit market adoption. While I understand the difficulties that a systems integrator must deal with and how frustrating it may be having your customer ask for the latest XXX chip with 150 lm/W when you selling a 30 lm/W fixture, I disagree that the rapid advancements are limiting.

Finally, with respect to the egregious claims hurting the LED industry, I concur completely. Customers that get "burned" by implementing a product with false claims will be reticent to try the product again. Results from the DOE's Commercial Product Testing Program (see page 8) support this.

So the solution, in my opinion – and which was echoed in the halls and driven home by the lighting designers such as James Benya – is that the LED/SSL industry needs some form of special interest group (SIG) with standards for its compliant members and a charter to educate its constituents. ●

About the author

Jed Dorsheimer serves as Vice President, Sr Equity Analyst at Canaccord Adams (www.canaccordadams.com) in Boston, MA, USA. Jed's knowledge of compound semiconductors and device physics has enabled him to build a unique franchise that focuses on identifying companies exhibiting disruptive technologies with defensible positions, either through IP or technical prowess, in the display and lighting markets. Canaccord Adams has published research recommendations on Cree and makes a market in the shares of the company. The comments in this article are not a recommendation to buy or sell the specific securities of the companies discussed.



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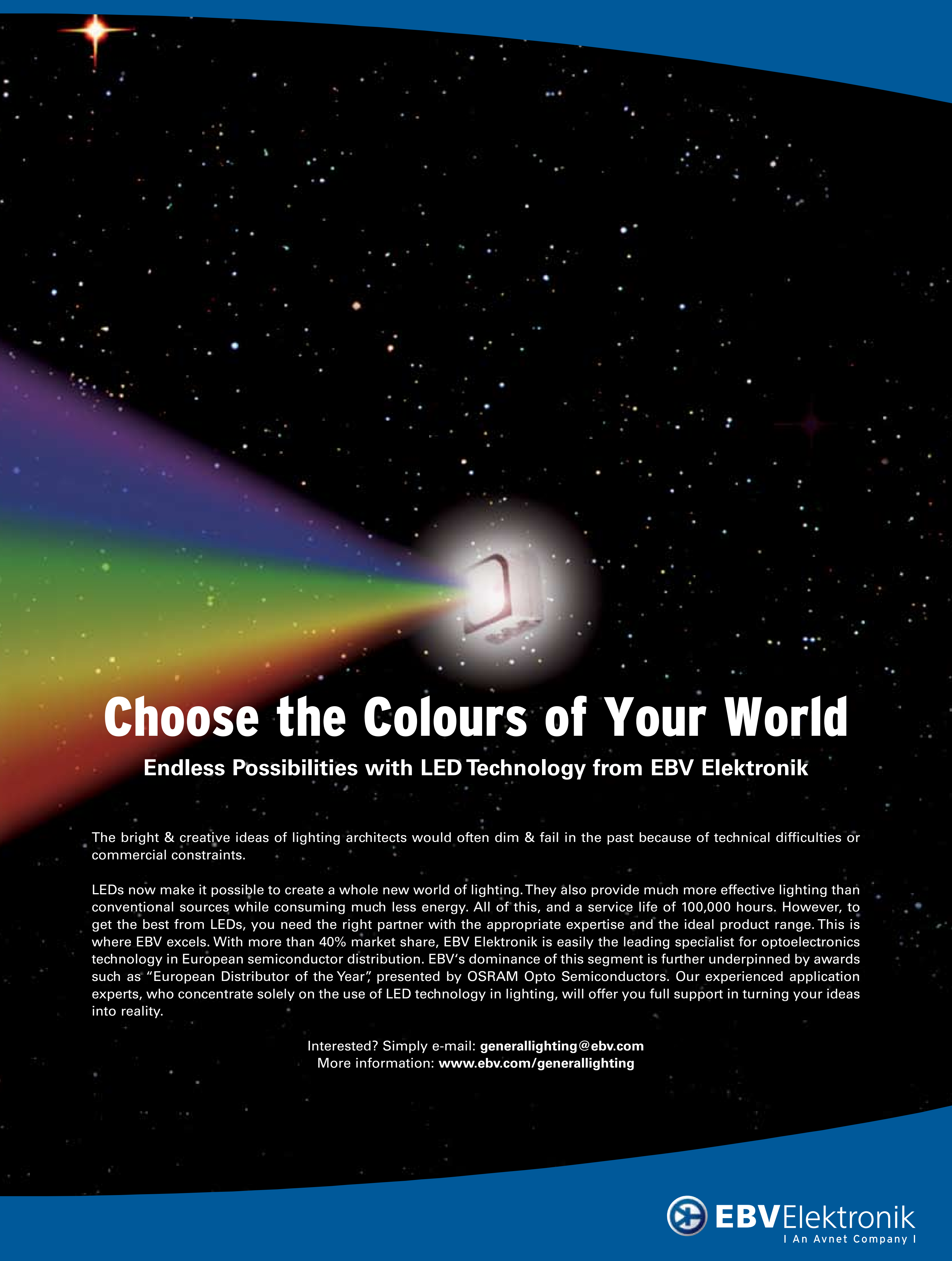
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The bright & creative ideas of lighting architects would often dim & fail in the past because of technical difficulties or commercial constraints.
LEDs now make it possible to create a whole new world of lighting. They also provide much more effective lighting than conventional sources while consuming much less energy. All of this, and a service life of 100,000 hours. However, to get the best from LEDs, you need the right partner with the appropriate expertise and the ideal product range. This is where EBV excels. With more than 40% market share, EBV Elektronik is easily the leading specialist for optoelectronics technology in European semiconductor distribution. EBV's dominance of this segment is further underpinned by awards such as "European Distributor of the Year", presented by OSRAM Opto Semiconductors. Our experienced application experts, who concentrate solely on the use of LED technology in lighting, will offer you full support in turning your ideas into reality.
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High-power LED arrays use optimized chip-on-board technology for brilliant performance

In order to reap the benefits of high-power LEDs, special requirements concerning thermal management and opto-mechanical layout have to be met, explains **Oliver Kückmann** of PerkinElmer Elcos GmbH.

Since 1962, when the first red GaAsP LED was produced at General Electric, a lot of time and money has been spent developing more efficient LEDs to compete with other light sources. Eventually, the development and serial production of so-called "power chips" or "high-current chips" came about in 2000, enabling LEDs to penetrate a variety of different lighting applications.

It should be realized that specific requirements must be met for developing such high-power LEDs. Most of the electrical input power is converted into heat, making thermal management a key consideration. Also, intelligent optical design of the LED is crucial as this enables increased efficiency and lowers the required electrical power.

While the efficiency of incandescent light sources is traditionally limited by the production of infrared radiation, LEDs are limited in conversion efficiency (electrical to optical) by non-radiative heat generation processes. To avoid damage to the LED's sensitive p/n junction, excellent heat conduction is needed throughout the entire LED assembly to dissipate this thermal energy to the ambient. Considerable effort is spent by LED manufacturers to increase the efficiency of every single component within the package, and all related components are chosen to achieve the highest radiant flux possible.

Fig. 1. PerkinElmer's ACULED (all color ultrabright LED) high-performance RGGB LED in COB technology.

Choice of LED chips

Chips are available in different sizes, and standard dies with edge lengths of 250–350 microns are available in nearly all wavelengths from 360 nm to 1000 nm. However, standard chips are limited to small forward currents (usually 20–30 mA) and this means that a large quantity of chips is required to achieve a high radiant flux assembly. The result is high bonding costs and low packing densities. Even so, these assemblies are favorable for different applications that do not require the highest luminous flux. With very close relationships to multiple chip suppliers, PerkinElmer Elcos can source these chips from a huge range of suppliers at very low cost.

High-current or high-power chips, with edge lengths ranging from 0.5 mm to 1.4 mm, are available from a few suppliers for limited wavelength regions. Typically, for drive currents of 350 mA or more, multi-watt or even multi-kilowatt LED arrays are possible, as described later.

Substrate materials

For high-power LED packages, an excellent thermal conductivity is important. Printed circuit boards (PCBs), typically manufactured using FR4 material or similar, have very low thermal conductivity of about 0.23 W/mK. Significantly higher performance is achieved using ceramic-based solutions, such as aluminum oxide (Al_2O_3) and aluminum nitride (AlN) with typical values of 25 W/mK and 180 W/mK, or metal core PCBs (MCPCBs). The distinguishing characteristics of the materials, including thermal expansion coefficient, thermal conductivity, and pricing, are carefully evaluated to meet customer needs and fit a particular application.

Chip-on-board

PerkinElmer Elcos uses a very promising packaging approach for high-power LED modules known as chip-on-board (COB) technology. Compared to individual standard LED packages offered by multiple LED suppliers, COB provides some major benefits.

The main advantage of COB solutions is their high packaging density, which can reach up to 85% (total LED chip size to overall size of the array), enabling minimized, compact packaging size. In comparison, typical values for single standard chip packages can be as low as 1–5%.

In COB technology, LED chips are bonded to a substrate that can be directly packaged on a heat sink or any kind of active cooling unit. This optimizes heat-flow and overall LED performance in a COB

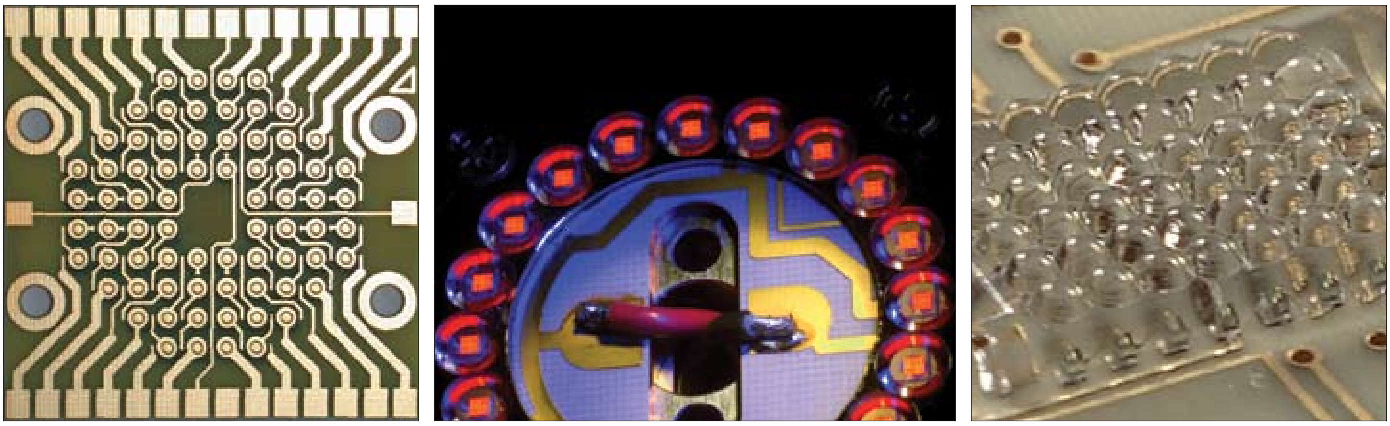

Fig. 2. Several COB solutions with different types of optical beam shaping elements produced by PerkinElmer Elcos.

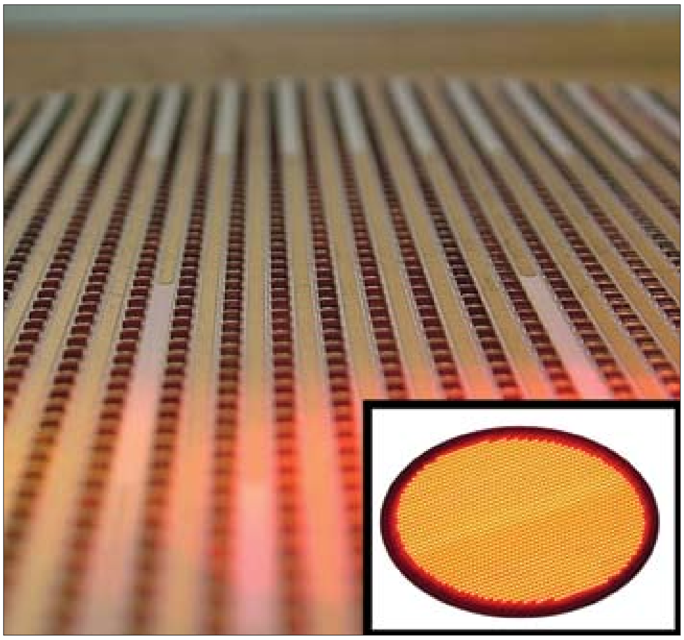

Fig. 3. The "3kW-LED" high-power COB array, with nearly 2000 1 mm chips, produced by PerkinElmer Elcos.

process. To produce a high-power array with standard single-chip packages, additional PCBs are necessary, reducing thermal conductivity and limiting lumen output.

In market applications requiring multi-color LED solutions, the close chip placement in COB technology offers another benefit – superior color mixing. The closest chip placement of 100 µm between the chips in the standard ACULED product shown in figure 1 underscores the ability to achieve the best color mixing, with or without additional beam-shaping optics.

Thermal management

The high packaging density of COB arrays presents a considerable challenge. For example, an array of LED chips with dimensions of about 1 × 1 mm^2 requires electrical input power of more than 1 W per LED. Since the junction temperature of the chips should not exceed 100 °C in order to ensure long lifetime and high optical efficiency, the generated heat must be dissipated. This is done via the carrier, substrate and heat sink. If heat dissipation is not done properly, the LED will show chaotic degradation, wavelength shift, loss of radiant flux, and reduction of forward voltage (V_f).

To meet customer requirements for a predictable optical output with a defined wavelength region in many applications, the temperature and working conditions are evaluated in order to select appropriate components for a COB package. This includes chip type and quantity, as well as the type and geometry of the substrate bonding materials.

If the chip, substrate (PCB) and heat sink are fixed, they have to be combined properly. This can normally be done by soldering, but most companies use high-thermal-conductivity glues. PerkinElmer Elcos, for example, achieves extremely thin and homogeneous adhesive layers – below 10 µm thickness – for achieving the highest LED performance. The mechanical stability and adoption of the glued components, particularly regarding the coefficient of thermal expansion (CTE), are vital considerations for a truly reliable system.

Efficiency enhancement of COB packages

Many LED lighting applications require high-power LED arrays and need defined irradiance. The broad aperture angles of most LED types, including COB LEDs, necessitate the use of additional optical elements. These demands can be fulfilled using primary optics, reflectors, or secondary optics.

Figure 2 shows several examples of COB assemblies. The first example places LED chips into embedded metallic cavities. The other examples show a custom solution with external reflectors and a solution with lenses on top.

The results of COB technology

Chip-on-board (COB) is a very attractive technology for packaging LEDs, especially for high brightness applications.

Excellent thermal management with adopted materials and highest efficiency throughout the LED assembly enable PerkinElmer to meet the most stringent customer requirements.

Figure 3 shows a high-power COB array that represents one of the brightest LED arrays ever realized. With nearly 2000 1 W LED chips contained in a lighting area with a diameter of approximately 120 mm, an LED was produced with a power consumption of more than 3 kW pulsed, or 25 W/cm^2. A very homogeneous light output of more than 200 W for a customized high-speed application impressively underscores the benefits of COB. ●

About the author

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LEDs create definitive lighting statement in the Lincoln MKR concept car

A star of this year's Detroit Auto Show, the 2007 Lincoln MKR concept features some very advanced lighting concepts enabled by LED technology, writes **Robert Miller**.

In designing the 2007 Lincoln MKR concept, unveiled at the NAIAS show in Detroit in January, Ford required an entirely new look and feel. For the first time LED lighting was at the very forefront of the overall design. The target was a rebirth of the Lincoln brand, with aggressive looks and advanced lighting technology. We had many hours of discussions on what the illumination visual statement would become, and it was decided to take some of the lighting design cues accomplished with the Super Chief (see *LEDs Magazine,* October 2006, p23) and blend them into the MKR.

It took over 100 hours to create a technology platform that could be used throughout the vehicle. The 2 W Osram Golden Dragon was chosen as the main LED platform, with features of high reliability, low profile with no lens, and wide latitude of color binning choices. In order to put the Lincoln MKR concept lighting in a class by itself, the rear tail-light was chosen as an exciting and unique lighting focus. The selected design required placing the LEDs in areas with less than 10 mm of clearance space, as well as making tight bends, twists and turns. To make matters more difficult, the circuit had to be mounted directly on the clear lens that covers each of the light chambers making up the rear tail-light. Temperature could not exceed 125 °F, otherwise the lens could start to deform, so managing the thermal needs of each LED was critical. 3M's Light by Wire (LBW) was the enabling component strategy that made the attainment of these design goals possible, while providing the Lincoln MKR concept with a spectacular and innovative lighting effect.

Robert Miller presents the unique LED-based rear-lighting design on the Lincoln MKR concept car at the Detroit Auto Show.

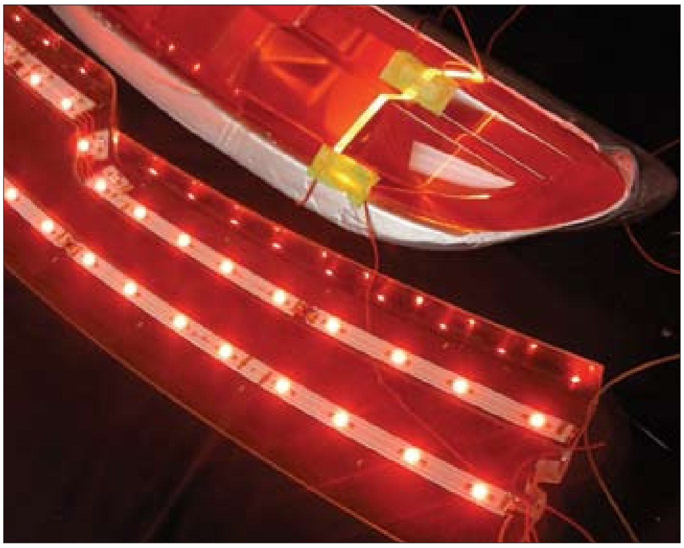
What is LBW?

LBW is a flat, multiple-width, flexible cable constructed of copper. It is over-extruded with a variety of coverings, making it right for many demanding applications. I like to call it flat-wire. The key is that it can be made in any width or thickness and in continuous lengths. When LEDs are placed on the LBW at the appropriate spacing for the application, the result is a complete, thermally stable, compact circuit. The overall finished height of the LBW with Dragon LEDs securely mounted is only 2.25 mm.


LED front lighting on the MKR includes a unique amber turn signal constructed with a lightguide bent around the headlamp.

Dimensional rear lighting

When illuminated, the rear lighting draws interest and creates a dimensional visual space that has not been seen before in traditional automotive lighting. Eighteen red cubes, each of which is an individual light chamber, are used to create the entire red rear lighting. Solid acrylic cubes were polished to a high gloss and painted (top, back and



Interior of the rear tail-light assembly showing Dragon LEDs mounted onto a thin, flexible Light by Wire (LBW) substrate.

bottom) with opaque red paint to create a reflecting chamber. The two sides and the front of the cubes were painted with clear candy-red paint, allowing light to escape. Each red cube is fed by four red Dragons, two on the top and two on the bottom. The running lights as well as the brake lights were controlled with two separate circuits.

Between each of the red cubes is a thin 8 mm spacer that receives light from two amber Dragons, forming the amber turn signals. Each spacer is highly polished with silver reflecting paint on the back, top and bottom in order to bounce the amber light out of the front.

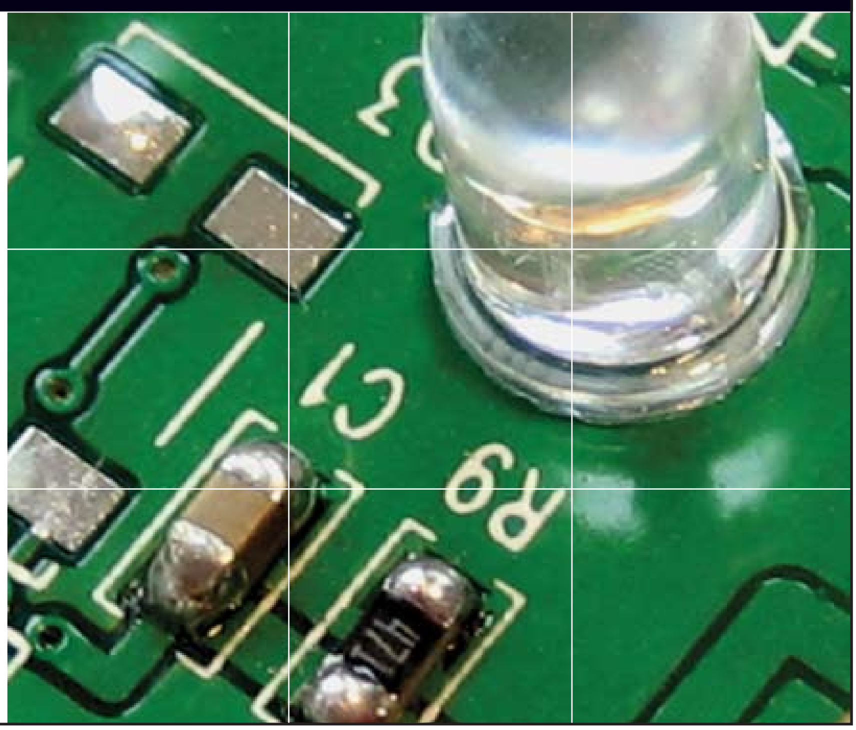
LBW was used to hold the LEDs, carry the power and to facilitate the bending and twisting to meet the design requirements. Traditional methods would not be possible. The magic of this design is that each cube is its own reflection chamber, and light focused into each cube glows and reflects out the front with high intensity. Because each cube has highly polished sides, light from one cube will not enter another. The amber spacers, when energized, appeared floating in space with sharp, delineated edges that add visual interest and appeal to the overall design.

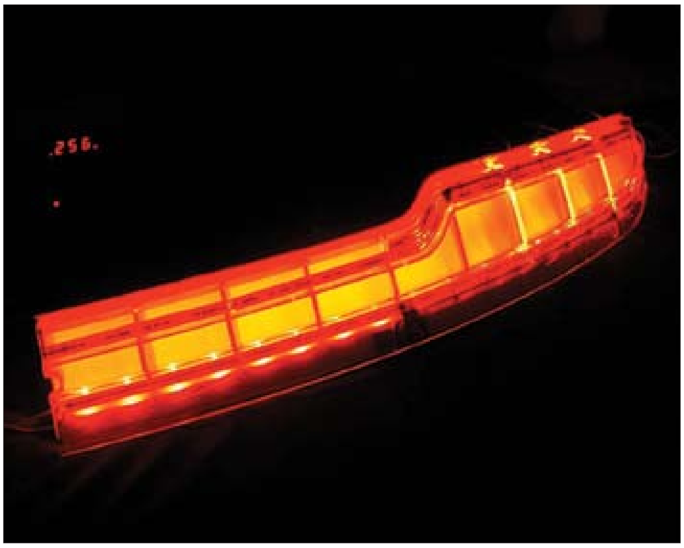
Interior mood lighting

Well-hidden mood lighting creates a unique ambience inside the Lincoln MKR concept. Ice Blue White lighting is carried throughout the high-contrast interior, emitting from the door panels, mohair-carpeted foot wells, seats, center console and perhaps most dramatically from the large Lincoln star in the headliner. Color-corrected Dragon LEDs that emit cool white, 7500 K light complement the champagne interior color. LBW was used in conjunction with a light guide to diffuse and soften the glow and to paint bluish-white light to specified areas within the vehicle.

Dimensional instrument gauges and cluster

The instrument cluster continues the dimensional look of the rear lighting, with chrome-trimmed gauges illuminated with Ice Blue. The gauges use LBW in a unique way. The three gauges are built around acrylic lenses. LBW containing four white Dragons is wrapped





Tail-light assembly showing the illuminated spacers that form the amber turn signal.

Acrylic lenses, LBW and LEDs create a dimensional look to the instrument cluster in the MKR concept.

around the edge of each lens, and the information to be displayed is laser-etched into the lenses. This technique is the first step to future designs using dimensional effect for gauges. LBW greatly reduced the required packaging space and performs with outstanding results.

Forward amber lighting

The amber turn indicators inside the forward lighting unit were also achieved by using a smaller version of LBW. Because of the small packaging requirement and the desire to have smooth, even lighting with no hot spots, it was necessary to place small LEDs very close together so that the projection beams would overlap. The lightguide width is slightly less than 7 mm and follows the shape of the top and bottom of the headlamp. LBW allowed LEDs to be fastened securely and easily bent around the shape of the lightguide. Designers have an increasing desire to have smooth flowing light that can outline various shapes in their designs. If the trend continues, LBW can serve as the technology of choice for future designs.

The remaining lighting elements – high and low beams – were created in conjunction with Decoma Lighting. These are unique lightguide elements capable of projecting an accurate beam pattern of light. Together with Decoma we designed a superb forward lighting package that helped Special Projects, Inc, the concept's builder, ultimately to produce a spectacular vehicle.

Summary

The Lincoln MKR concept is in a class by itself and comments from the crowd and the media at NAIAS were indeed positive, especially on the lighting side. As Ford's chief designer Gordon Platto stated to the media: "Lighting is an important design element, we know customers are paying more attention to the lighting in their homes than ever before, and we wanted to leverage it to create even more ambiance and drama inside and outside the concept."

Over the next several years, lighting will become as important as the design of the vehicle. The results are very evident with the new interior lighting packages on production vehicles such as the 2008 Ford Focus and the Chrysler Town and Country minivan. You can expect to see more innovation as all these technologies mature, gain acceptance with the automotive design community and ultimately create new looks never seen before. ●

About the author

Robert Miller (email: lighting@conceptdesignlighting.com, tel. +1 734 255-0300) is owner of Concept Design Lighting (www.conceptdesignlighting.com) and former owner of BrightLights Technologies, LLC. He has successfully designed and delivered more than 125 advanced lighting programs and completed more than 22 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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OLED light sources advance towards the lighting market

Organic light-emitting diodes could soon open up a whole new range of lighting applications if their current pace of research and development continues, writes **Siân Harris**.

Furniture designers and architects could have a whole new medium to play with if the expectations placed on organic light-emitting diodes (OLEDs) are realized. This emerging lighting technology using organic light-emitting materials, a counterpart to conventional semiconductor-based LEDs, could open up new application areas for lighting if it moves from its current R&D status to commercial products.

Unlike incandescent bulbs, halogen lamps and LEDs, which are all point sources, OLEDs are flat-area sources: they emit light uniformly from everywhere on their surface. This means that diffuse, glare-free lighting effects can be created without the need for special screens, mirrors or reflective ribs, such as those used to diffuse the light from fluorescent tubes. And, if the industry goals are realized, these new lights should eventually far surpass many current lighting technologies in energy efficiency, lifetime and color rendering.

Eventually, the lighting industry hopes that this new OLED technology will compete with the fluorescent and incandescent lamps that currently light up offices and homes, complementing point-source technologies, such as LEDs. Before these mass-market applications occur, OLEDs could find their way into any number of smaller and more specialist lighting applications, such as illuminated signs. Of course, they have already penetrated the small display market and are seen in MP3 players and secondary displays in mobile phones.

What's more, other features of OLEDs could open up new lighting applications. They can, for example, be made transparent, so the window of a house or a car sunroof could double up as an OLED light source at night. Recent demonstrations have already shown 80% transparency, so this capability is expected to become feasible in a few years' time. Similarly, with the right substrate, OLEDs could be made flexible, creating all sorts of new possibilities for lighting designers.

Bernhard Stapp, CTO of Osram Opto Semiconductors, says that OLEDs "could be a new aesthetic design element. They could combine mood lighting with illumination." Peter Visser of Philips Lighting, who leads the European OLED research initiative OLLA, has also observed excitement about the design potential of OLEDs. He recently spoke at an Italian workshop for architects and found that about 200 of the delegates turned up to hear about OLEDs. "This was even more than at recent technical conferences," he pointed out.

Despite the enthusiasm for potential applications, OLEDs for lighting are still at the R&D stage and all of the key parameters require some level of further development.

COURTESY OF PETER VISSER, OLLA AND PHILIPS

OLEDs may emerge as a major light source for the next generation.

Beating incandescent lights in energy efficiency

Perhaps the most talked-about feature of OLEDs is their potential for energy efficiencies that could ultimately reach as high as 170 lm/W. Right now, white OLEDs are on an upward path similar to that of white LEDs, which are approaching 100 lm/W in production.

Several manufacturers have reported white OLED efficiencies of about 30 lm/W at brightness levels suitable for lighting applications. Leading the field is Konica Minolta in Japan, which has reported an efficiency of 64 lm/W for white OLEDs. According to Yuko Ogiso of the company's corporate communications team, this demonstration was done using laboratory samples that gave a brightness of 1000 cd/m^2, with a color rendering that is almost good enough for lighting applications and a lifetime of 10 000 h. Ogiso says that the company believes that these conditions could be reproduced commercially.

For the individual colors, even higher efficiencies have already been achieved. Green OLEDs, for example, have been demonstrated with an energy efficiency of 110 lm/W.

The figures for white OLEDs already compare well with traditional lighting technologies. Incandescent bulbs have efficiencies of about 12 lm/W, halogen lights are about 20 lm/W and fluorescent tubes are 60–100 lm/W. Nonetheless, OLED proponents believe that something higher – in the region of 50 lm/W – is likely to be required for most entry-level applications. This would be similar to the high-power compound semiconductor LEDs that are on the market today.

Lifetime

The second issue for OLEDs is lifetime, and this is an area that Sven Murano, who leads the project for white light development for German OLED specialist Novaled, believes the technology is addressing well. "OLEDs have really developed fast in terms of lifetime," he explained. "At 1000 cd/m^2, which is the approximate brightness that would be

OLLA AND PHILIPS

High-quality white light is emitted by OLED materials without phosphor conversion, as shown in this Philips demonstrator.

OSRAM

Osram Opto Semiconductors has demonstrated a white polymer-based OLED with an efficiency of 25 lm/W. The cool-white device was produced by applying a standard, orange-emitting, external inorganic phosphor to Osram's blue-emitting phosphorescent polymer device with a peak luminous efficacy of 14 lm/W. The work is part of a project funded by the US DOE to the tune of $4.65 million, matched by equal funds from Osram.

required for lighting, Novaled is currently at a lifetime of 20 000–30 000 h, which is already several years." He believes that several tens of thousand of hours should be suitable for most applications and would compare well with the lifetime of about 10 000–15 000 h for a fluorescent tube. These figures are not entirely comparable, however: the lifetime for fluorescent tubes and other high-intensity discharge (HID) lamps is defined as the time before its brightness drops to 80% of its initial level, whereas the brightness of an OLED is defined as the time until it has only 50% of its initial brightness.

Despite encouraging reports of OLED lifetimes, this could be pushed to its limit for some applications. "An OLED is a high-quality product so people will expect a long life. You could imagine it being installed in a wall and not being changed for years," said Murano.

The issue of lifetime is complicated further because there is a need to take into account the length of time that the product might be on the shelf before it is purchased, or how long it must last when it is not being operated. "The operating life of OLEDs starts from a couple of thousand hours, but we will also need a long shelf life, especially if we are talking about integration into furniture," pointed out Osram's Stapp, who explained that creating an OLED with a very long lifetime is not difficult, provided that the cost can be justified. Today's OLED displays have very good shelf lives but considerable money is spent on having very effective encapsulation schemes – something that is unlikely to be justifiable for a product that has to compete in the same market as lighting fixtures that use standard incandescent bulbs. "One of our goals is to find a very effective but low-cost encapsulation scheme," he said. Effective encapsulation is an important contributor to the lifetime because OLEDs are both air- and moisture-sensitive and would only last a few hours if they weren't protected.

Color and size

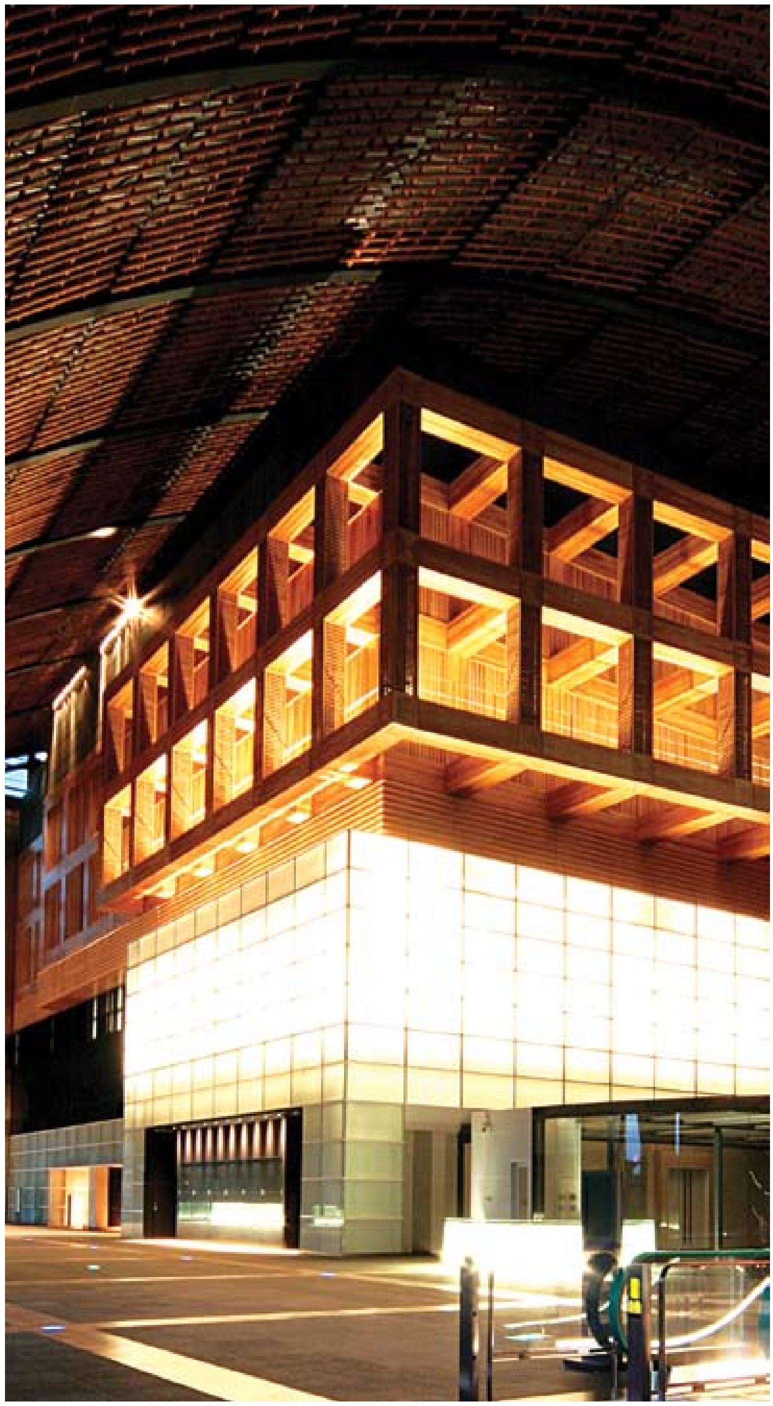
In addition to the costs associated with the encapsulation of the OLED, the lifetime of a white OLED depends on the wavelengths of the different-colored emitters that are stacked on top of each other to produce white light. Red emitters already have lifetimes of at least 1 million hours but blue emitters pose a tougher challenge. "These materials have to fulfill many requirements, such as being stable to deposition in the gas phase and under the appropriate driving conditions," said Stapp. "It is tough to realize this with blue organic emitters."

"We're all looking for an efficient, long-living, phosphorescent deep blue – the OLED equivalent of Nakamura's discovery of GaN for blue inorganic LEDs," agreed Philips' Visser. "With such a blue source, combined with a yellow, very good white OLEDs could be generated." Whether the current blue materials are good enough already very much depends on the type of application. For example, says Visser, emergency exit signs are governed by legislation specifying a lifetime of 25 000 h. This is quite hard to achieve with today's white OLEDs.

The different-colored OLEDs fare better in the contributions that they make to the color rendering of white light sources. This is an important feature of any lighting scheme – when people buy a dress they want it to look the same color in the shop as when they take it out into natural light. "For decent lighting applications you need a color rendering index of 80 or above," explained Visser. "High-pressure sodium streetlights give a color rendering of about 30, which is why it can be hard to find your car in a large car park lit with these yellowish lights." In the area of color rendering, the incandescent bulb currently excels but fluorescent tubes and inorganic LEDs tend to perform less well. OLEDs can easily produce a high color rendering because they are broadband emitters.

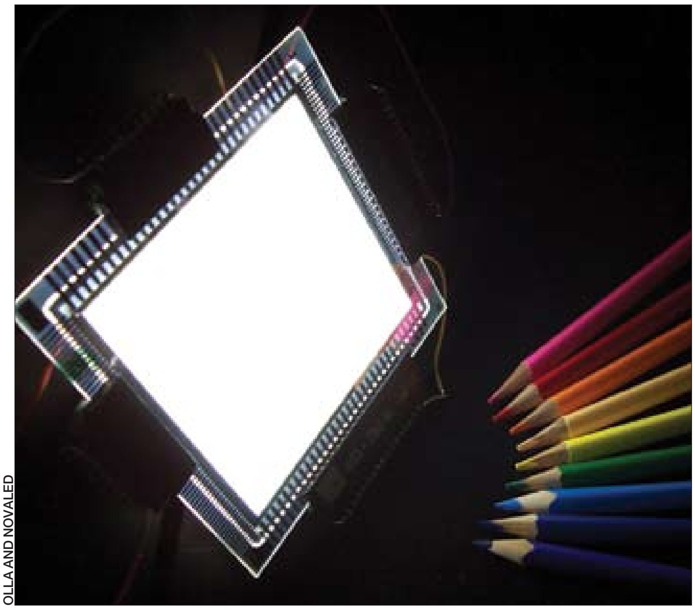
Another issue that needs to be addressed is the size of OLEDs. Although they emit homogenously from their whole area, they are still small. Current laboratory models are generally around 10 or 20 cm^2, although at the recent Plastics Electronics conference in Frankfurt, Germany, Takuya Komoda of Matsushita's Advanced Technologies Development Laboratory described a 30 cm^2 single white OLED panel that was not made up of any arrays or pixels.

OLEDs need to have a certain size to give a decent amount of light. Although the light output per unit area (i.e. the brightness) increases as the current goes up, this also decreases lifetime and efficiency. Early applications are likely to use arrays of small OLEDs. However, in the long term the size of individual OLED panels is expected to increase as manufacturing equipment is scaled up from the laboratory to the production environment.



OSRAM

Osram has demonstrated tunable polymer-OLED light sources based on three separate, printable polymer inks emitting in the red, green and blue parts of the spectrum. Using inkjet printing to pattern small three-color segments, along with the product's unique driver circuitry, users can regulate the color from dark blue to white.



OLLA AND NOVALED

A $7\times7\,cm^2$ two-color fluorescent white PIN OLED produced at Novaled on an IPMS ITO Al grid substrate.

Using experience from displays

This scaling-up stage will be a vital step in the commercial plans of all OLED firms. "A low-cost mass-production process is indispensable for getting OLEDs to market," said Konica Minolta's Yuko Ogiso.

The journey towards commercializing OLED lighting can, in part, benefit from the fact that displays based on OLED technology are already in use commercially, and some of these are based on white OLEDs with color filters. However, there is not as much potential for reusing techniques as might be expected. Osram's Stapp pointed out: "The process and production of displays is much too expensive for light sources. We need new ways [of producing OLEDs for lighting] and we are still a way off from this." The main costs involved in producing OLED displays are largely related to the substrate cost, the need to pattern the substrate, and the deposition and bill of materials for the encapsulation scheme to avoid contamination of the electrode, he explains. OLED lights are simpler than displays, so many of these costs can be reduced significantly. For example, the advanced patterning that is required for displays, in order to create individual pixels on the screen, is not a stringent demand for lighting. This means that manufacturers can perform area deposition. In addition, unlike displays, OLED lights do not require a back plane.

Although the relative simplicity of OLED lights compared with displays is an advantage, the OLED lighting market is hampered by cost. Janice Mahon, who is responsible for the chemical supply business and corporate marketing for US-based Universal Display, explained: "The costs that people expect to pay for lighting are around two orders of magnitude lower than what they expect to pay for displays." In other words, they are prepared to pay far more to replace a television screen than to replace a light bulb.

Mahon also believes that the production quantities will have to be very large – of the order of millions of units – for OLED lights to penetrate the market significantly. This will have a considerable impact on production. "In my opinion, to get to commercial volumes, we would need meter-wide substrates or more," she said.

There is also general agreement that the production tools for OLED lighting will have to be different from those for displays. "We will need to evolve from batch processing using cluster tools to high-throughput roll tools," said Mahon.

Progress is already being made in these areas, according to a paper by Svetlana Rogojevic and Anil Duggal of GE Global Research that was presented at the Plastic Electronics conference in Frankfurt. They reported that work is under way on a roll-to-roll fabrication line to laminate OLEDs onto a plastic substrate that will be ready in 2007. Early tests have shown that the method works, according to the researchers. However, better adhesion is needed for large-area devices.

The development of such processes will play an important role in developing new features of OLEDs, such as transparency and flexibility, because these all present additional design challenges. Flexibility requires moving away from the existing glass substrate while transparency needs a new stack design and electrodes.

Meanwhile there are further issues that need to be ironed out in developing commercial processes. The quantity and quality of the starting materials need to be stable, for example, and work is still going on to determine the best materials to use and the best ways to deposit them. More work is also needed to understand the structure of OLED lighting devices and how to enhance the light output in the desired direction – only about 30% of the light comes out of the front of the OLED unless foils and other techniques are used to reduce the internal reflections. And the use of these foils requires a trade-off – enhancing one wavelength causes a penalty for another wavelength.

"To put products into the market we need the whole chain to be well established," commented OLLA's Visser. "To go from the research stage to full production always takes a certain amount of time."

Working together

Initiatives such as OLLA (High Brightness OLEDs for Lighting Applications), which began in 2004 and will run till mid-2008, can play a key role in helping the industry to get to this production stage. By the end of this European project the 24 participants aim to demonstrate a white OLED with an efficiency of 50 lm/W, a lifetime of 10 000 h – 10 times as long as a standard incandescent bulb – and a color rendering index of 70. "If we can achieve this for OLEDs then this will be a clear indication that this is a lighting technology. We are now around the performance levels of halogen lamps," said Visser.

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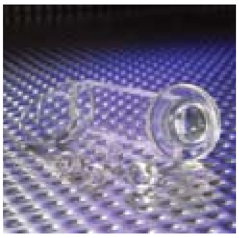

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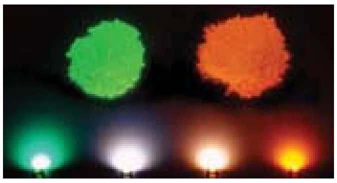
INTEMATIX CORPORATION

Green and orange phosphors

Commercial products of high-efficiency green and orange phosphors have been successfully developed by Intematix Corporation. The photo shows applications using these phosphor products for green, cold white, warm white, and orange LEDs. A series of green phosphors (G2762, G3161 and G3560) were designed for peak emission ranging from 515 nm to 540 nm under excitation below 460 nm. A series of orange phosphors (O5446, O554, and O5742) were designed for peak emission from 585 nm to 610 nm.



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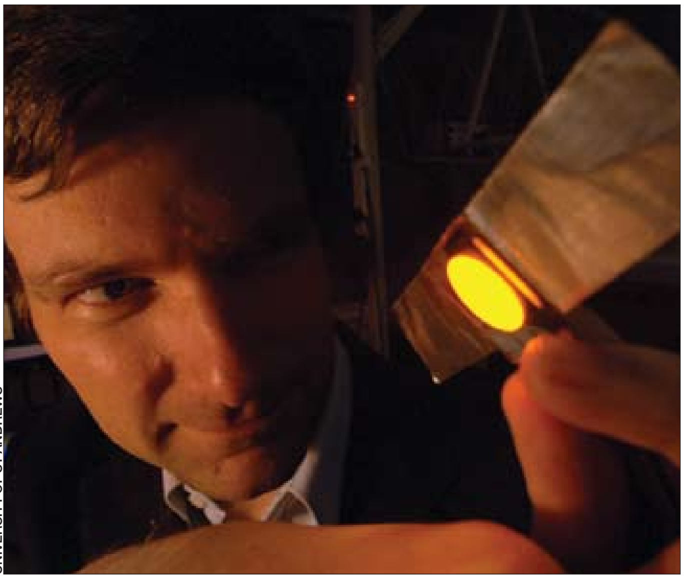

Medical applications: Prof. Ifor Samuel of the University of St Andrews, UK, demonstrates a "light bandage" containing a 2 cm diameter OLED emitting at 590–630 nm with an output of a few milliwatts per square centimetre. The OLED is used in photodynamic therapy treatment of certain types of skin cancer (see www.ledsmagazine.com/articles/news/3/11/1).

Work towards this goal falls in a number of different work packages. Around 30–40% of the OLLA project is devoted to new materials. Any promising materials are then passed on to those working in the device-making work package. Other project participants are involved in modeling OLEDs and looking at issues such as layer thickness and ways to enhance the light output. A further work package focuses on encapsulation methods, ways to make thin film encapsulation and lifetime-prolonging driving systems. Finally, some participants are looking at novel deposition methods and ways to gravure-print OLEDs onto the substrates.

Nearly half of the 24 partners in OLLA are from Germany, but the German government has also invested heavily in OLEDs by launching a national project to look at this area. The OLED 2015 initiative is funded to the tune of €100 million over the next five years by the BMBF, with an additional €500 million coming from the 33 partners.

According to Murano of Novaled, which is involved in both projects, the European and German efforts are complementary. "The projects within the German initiative tend to be more specialized and have fewer partners than OLLA," he explained. "The German initiative's focus is on specific tasks, such as methods of production or OLEDs in automotive applications, while OLLA's target is much broader." Murano believes that such initiatives are good for the industry. "They raise awareness of different technical issues and trigger development inside companies, and there is a strong cross-fertilization of ideas," he said. "It also helps to educate more experts in the field, which is important because it is very new." Elsewhere in the world other governments have similar ideas. In the US, the Department of Energy's solid-state lighting (SSL) initiative has set a performance goal for OLEDs of 150 lm/W by 2020, and it has developed a roadmap to get there. The SSL initiative consists of independent projects with one or two partners rather than the big collaborative efforts such as OLLA that fall within the European Framework. However, Universal Display's Mahon said that her company receives DOE funding but also has strong links with others in the industry, such as Toshiba and Konica Minolta.

Standards could help comparisons

Co-operation between different industry players, whether within an initiative or as part of a commercial partnership, could help the industry in another important step towards commercial products: standardization. Visser believes that OLLA could help with standardizing the fixtures and developing a clear message about the characteristics that will define OLEDs to customers. "At the moment there are a lot of press releases about companies achieving certain performance criteria but there is always some part missing. For example, although Konica Minolta announced an efficiency of 64 lm/W earlier this year, it has not published any scientific results so far. This makes it very hard to make comparisons with what has been going on elsewhere in the world," he said. "It would be nice if everybody published their scientific data. You shouldn't confuse the market at this early stage." With such issues in mind, OLLA is thinking of publishing a standard for OLED lighting measurements so that people can better compare them. For example, if you put a big glass block in front of an OLED, more of the light would go forwards so the measured light output would be higher. "It would be like measuring the performance of an LED at very low temperatures. You can get far better performance in a lab than you can see in commercial products," he pointed out.

Outlook for OLEDs...and LEDs

So where does all of this leave conventional LEDs? Reassuringly it appears that OLEDs will have far less effect on LEDs than on the traditional lighting technologies. Most in the industry regard the two technologies as complementary. Conventional LEDs are point sources and so are the best choice for applications such as car headlights, torches and downlights. As area sources, OLEDs are likely to be used as display and panel backlights, for ambient lighting and eventually for general illumination, although the lighting fixtures are likely to have a very different appearance from those that we see today.

One benefit that conventional LEDs certainly have over OLEDs, however, is their relative maturity. While OLEDs, which were only discovered in 1987, are still going through the painful process of scaling up from R&D to manufacturing and trying to keep the costs down, white LEDs are already tackling a number of lighting applications.

Nonetheless, companies involved with OLEDs are predicting that early OLED applications will emerge over the next couple of years. "We predict low volumes of OLED backlights for LCDs around the end of 2007/2008," said Sven Murano of Novaled. "We really need a few more years before [OLED technology] becomes visible to consumers though. In the next 10 years we anticipate that OLEDs will become one of the major lighting technologies." ●

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Links

OLLA: www.olla-project.org
DOE solid-state lighting program: www.netl.doe.gov/ssl
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OLLA project reports OLED lighting milestones
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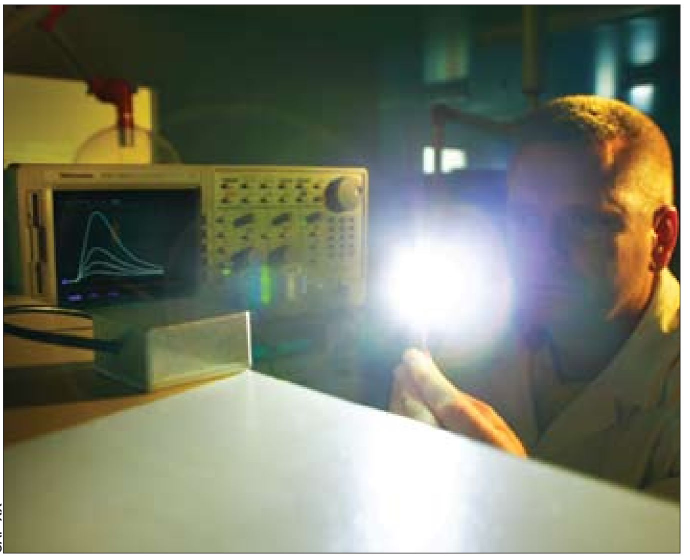
Supercapacitors brighten prospects for power LED flash in camera phones

The combination of power LEDs and supercapacitors could provide the crucial breakthrough that will enable high-quality LED flash in camera phones, with low current draw and small form factors. **Siân Harris** reports.



CAP-XX

Trevor Smith of CAP-XX sets up the light measurement equipment.

Although some of today's camera phones have good quality lenses, image-processing software and high numbers of pixels in the image sensor, there is one big area of development required to complete the picture. Few camera phones are able to take photos at the low light levels that users experience in restaurants, bars or inside their friends' homes.

The key to taking good pictures in these environments is to produce enough light energy from the flash while the picture is being taken. One measure of light energy is derived by summing the illuminance of the light source (measured in lux) over the duration of the flash exposure time. A light energy of 10–15 lux.sec is thought to be ideal for high-resolution pictures at low light levels.

Many camera phones already use LEDs to provide some flash functionality, but these have not proved equal to the task as they do not provide enough light energy to illuminate their subjects sufficiently. Most of today's phones with LED flash drive the LEDs at 1–2 W and provide less than 4 lux.sec of light energy at a distance of 1 m from the phone to the subject, and less than 1 lux.sec at 2 m.

Higher power LEDs would seem like the next obvious development. However, to achieve full light intensity, these require up to 400% more current than the 800–1000 mA that a phone battery can usually provide for LED flash.

Xenon flash

As an alternative to LEDs, some of the latest camera phones with high-specification cameras carry xenon flash tubes that are driven by electrolytic storage capacitors. Xenon flashes give excellent light output with a very short flash exposure time, ideal for freezing motion and illuminating objects at longer distances.

However, xenon flash tubes require large electrolytic storage capacitors, making them bulky. In the SonyEricsson K800 phone, for example, the xenon flash and its peripherals occupy a total volume of about 3.8 cm^3. There are also safety concerns about storing 1.5 J of energy at 330 V, particularly near the ear. Furthermore, the electrolytic capacitor takes a long time to recharge between photos (around 8 s for the SonyEricsson K800) and cannot be put to any other use within the phone.

However, this is not the end of the options available. Technology developed at Australia's CAP-XX is enabling camera-phone companies to look differently at high-power LEDs. The company specializes in thin-form supercapacitors for consumer electronics applications and saw the opportunity to combine these with high-brightness LEDs.

In CAP-XX's LED BriteFlash architecture, supercapacitors deliver the pulse current (more than 1 A) that is needed to operate the high-power LEDs. The camera phone's battery is only required to recharge the supercapacitors between pulses.

According to CAP-XX's vice president of applications engineering, Pierre Mars, if a 0.5 F supercapacitor discharges 1 V during the flash pulse then it only requires 250 mA of charging current to recharge it in 2 s ready for the next photo. This figure is well below the current levels required for today's standard LED flashes.

Light energy comparison

With this approach it is possible to deliver more light energy than most xenon flashes, according to a recent technical study by CAP-XX. The company looked at the ability of xenon flashes, standard LEDs and its LED BriteFlash to provide the necessary light energy for camera phones of 2 megapixels or more to take digital-still-camera-quality pictures at low light levels.

The study included three different xenon-flash camera phones with different sized electrolytic storage capacitors. In addition, the Nokia N73 was used as an example of a standard LED flash. The BriteFlash approach was tested using a combination of two 17×28.5×1.6 mm supercapacitors and either two or four high-current Luxeon PWF1 LEDs. The supercapacitor drove these LEDs at 1 A each.

Photos taken in low ambient light conditions at a distance of 2 m from the girl using (left) a 1 W LED flash and (right) a camera phone modified with a supercapacitor to drive 4×PWF1 LEDs at 0.9 A each for a total flash power of 15 W.

Table 1. Results from CAP-XX's evaluation of different flash sources over a distance of 2 m

Source	storage capacitor	peak light power (lux)	exposure time (ms)	light energy (lux.sec)
Xenon, SonyEricsson K750	60 µF	97 000	<1	9.5
Xenon, SonyEricsson K800	2×14 µF	53 000	<1	4.2
4×LEDs @ 1 A each	0.55 F	175	67	10.8
2×LEDs @ 1 A each	0.55 F	86	67	5.3
LED, Nokia N73	NA	5	90	0.43

CAP-XX

With all of these flash approaches, a photo detector measured on-axis illumination while a digital storage oscilloscope captured light power over time at distances of 1 m and 2 m from the source. The areas under the power curves were integrated to measure the light energy at the detector as a function of time.

Study results

Table 1 shows the results of this study at a distance of 2 m. Only the BriteFlash approach using four power LEDs and an exposure time of 67 ms gave a light energy level above the ideal 10 lux.sec threshold. The best-performing xenon flash of the three studied (on the SonyEricsson K750 camera phone) gave a light energy of 9.5 lux.sec but this was achieved with an external flash accessory with 60 µF capacitance. The Nokia N73 containing a standard LED flash produced a very low light energy of 0.43 lux.sec.

From the study results, CAP-XX believes that the BriteFlash architecture offers other benefits over xenon flashes. Because of the company's thin-form (less than 2 mm) design approach, the supercapacitor fits more easily into a slim mobile-phone handset than the electrolytic storage capacitor that is required for xenon flashes. CAP-XX's technology also addresses the safety concerns about the high voltages in xenon flashes: the µF-level electrolytic capacitors used with xenon flashes have voltages of 330 V, but the BriteFlash approach, with 0.55 F capacitors, uses a voltage of just 5 V.

In addition, the supercapacitors for the flash can help out with the power management in other mobile-phone functions that require peak power, such as wireless voice and data, music audio, GPS readings and mobile TV. This could improve the battery lifetime for the entire phone. The LEDs themselves can also be used continuously for making video clips or to provide a flashlight (torch) function.

One area in which xenon flashes are clearly superior is in taking action photos. While the BriteFlash approach delivers the required amount of light energy over a longer flash exposure time (up to 67 ms), xenon flashes deliver very high peak light powers (up to several hundred thousand lux at 1 m) in a very short amount of time (typically 50–100 µs). This means that they can be used to take action shots in low light. Such photos would be blurred with the BriteFlash approach, although blur problems caused by camera shake over this longer exposure time can be ironed out with image-processing software.

Despite this disadvantage of the LED and supercapacitor approach, CAP-XX is optimistic about the potential of this technology. "We are working with key mobile-phone manufacturers and expect the first designs that are power-boosted by our supercapacitors to hit market late 2007 or 2008," said CAP-XX's CEO Anthony Kongats. ●

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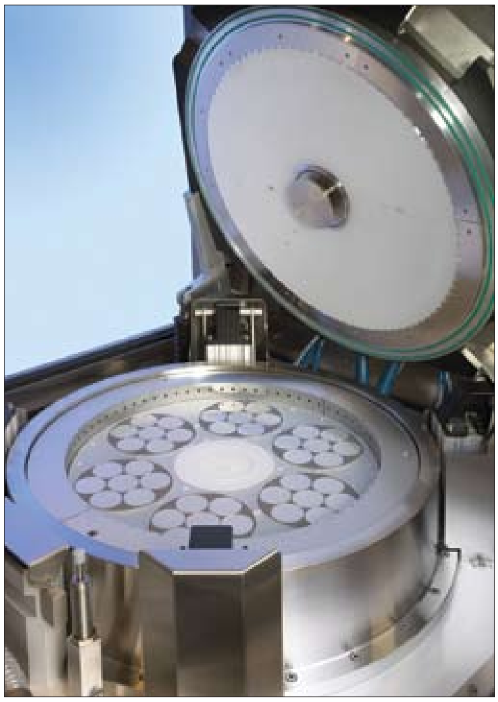
MOCVD growth systems respond to demand for higher LED productivity and yield

Manufacturers of equipment used to grow LED layer structures have introduced new systems capable of depositing even more material in a single run, in response to customer demand for higher throughput and more cost-effective production. The new MOCVD systems introduced by Aixtron (Aachen, Germany) and Veeco (Somerset, NJ, USA) can grow gallium nitride-based LED layer structures on as many as 42 or 45 two-inch wafers, respectively, while each offering different attributes.

LED chips are composed of multiple layers of different semiconducting materials, which are deposited onto circular wafers inside a metal-organic chemical vapor deposition (MOCVD) system. This process, known as epitaxy, is critical for determining LED performance characteristics and therefore influences binning of white LEDs.


The new G4 machine from Aixtron can grow LED structures on 42 two-inch wafers in every run.

Rainer Beccard, Aixtron's director of marketing, says that the first AIX 2800G4 Planetary Reactors from Aixtron are now operational at customer sites in Asia, and that a double-digit number of machines have been sold. With a capacity of 42 two-inch wafers, and based on the modular IC (integrated concept) platform, the system has almost double the capacity of the company's previous-largest machine.

Veeco's latest TurboDisc K-series MOCVD platform has two models, the K300 and the K465, and the latter can hold 45 two-inch wafers. Sudhakar Raman, VP of marketing with Veeco's MOCVD division, says the K-series is a multi-generational platform that gives significant productivity increase. The K300 can be upgraded by changing to a larger growth chamber, protecting the initial capital investment by the customer. Veeco says it has received orders for five new systems from three leading manufacturers of HB-LEDs, with a total value of around $10 million.

Raman says that among many issues surrounding MOCVD growth, two are key, namely productivity and yield. LED manufacturers are keen to increase both. Doubling the amount of material that can be deposited is a good start, if this can be done in a uniform and reproducible manner.

Higher productivity

It is reasonable to estimate that around 15 000 standard-size chips (300 micron square) can be grown on a two-inch wafer, taking into account wastage at the edges of the wafer. Typical power chips (1 mm square) occupy at least ten times the area, so around 1500 per wafer can be expected. Numbers vary widely depending on process conditions, but using ballpark figures of 40 wafers per growth run, three runs per day and 300 days operation per year gives an annual total of 540 million standard size chips, or more than 50 million power chips. That's for each of the new generation machines. Of course, this does not take into account how many chips fall into the desired wavelength bins.

Generally speaking, more chips can be produced from larger wafers. Although the mainstream of GaN LED manufacturing is still two-inch, there is a big interest in three- and four-inch, says Beccard; "The first systems for such wafer sizes are already installed. This is driven by the move towards larger LEDs, as well as cost reduction issues."

Yield and repeatability

As far as yield is concerned, MOCVD is a very complex process, explains Raman. "There are a large number of variables to control," he says. "Three different customers growing the same layer structure will come up with different results. It's almost like cooking." Essentially, the key features of the chip, such as wavelength and forward voltage, are defined by the MOCVD process.

Beccard says that the real chip yield is basically determined by the uniformity on each wafer, from wafer to wafer and from run to run. "We have a novel gas inlet geometry which leads to more uniform gas-phase distribution and increased stability between runs. At the same time we have optimized thermal conditions inside the reactor, resulting in better reproducibility. Finally, in-situ monitoring devices help to monitor and control physical properties of the [LED] structures while they grow, thus improving yield."

Likewise Veeco cites numerous improvements in its latest machines, including its patented real-time closed-loop in-situ temperature control mechanism for excellent uniformity and repeatability, and both companies say they have been influenced by the market requirements for backlight units for LCD screens. This market requires tougher wavelength selection (in order to achieve the required white point), higher brightness and efficiency, high volumes and reduced cost. Going forward, demand will increase from car headlights and general illumination. "Again we will have to adjust our reactors to the requirements that are related to these future applications," says Beccard. ●

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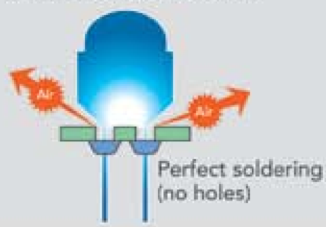
The Only LED Lamps with a Pressure Release Structure (SLI / R-343 Series).

No Retouch Soldering

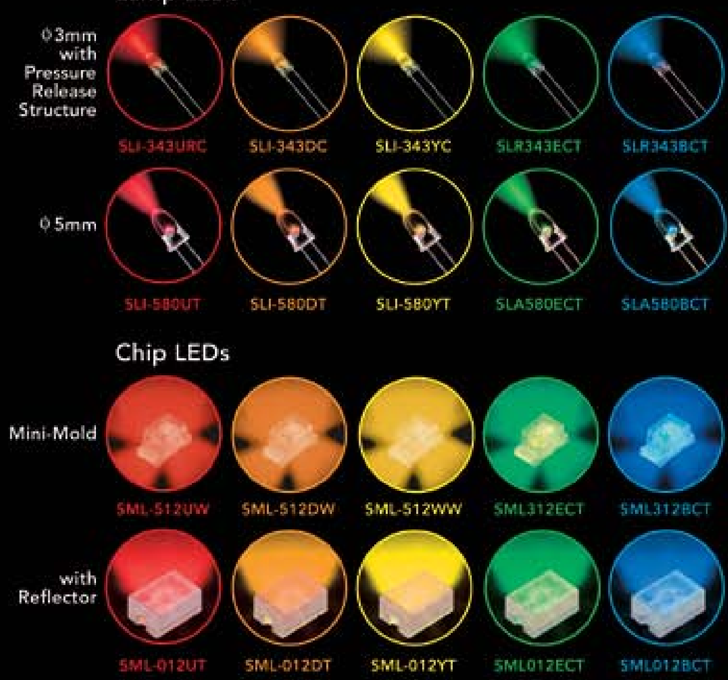
ROHM's pressure release structure prevents pressure build-up during the soldering process when the LED is mounted on the PCB.

Conventional Product

ROHM's SLI/R-343 Series



Pick a color. ROHM's ultra high bright LEDs are available in many luminous colors.



Wide Directivity

ROHM's φ3mm LEDs feature a directivity equivalent to that of φ5mm LEDs (luminous intensity half-power viewing angle approximately 40°).

Many Luminous Colors

ROHM offers an LED lineup in a variety of luminous colors using both AlGaInP (a proprietary compound) and InGaN.

A Broad Lineup of LEDs

- Right angle chip LEDs
- Reverse mount chip LEDs
- Low current chip LEDs (ideal for portables)
- Dual color chip LEDs
- LED lamps with pressure release structure
- Direct mount LED lamps

Excellence in Electronics

ROHM

1.888.775.ROHM   www.rohmelectronics.com