JUNE 2011

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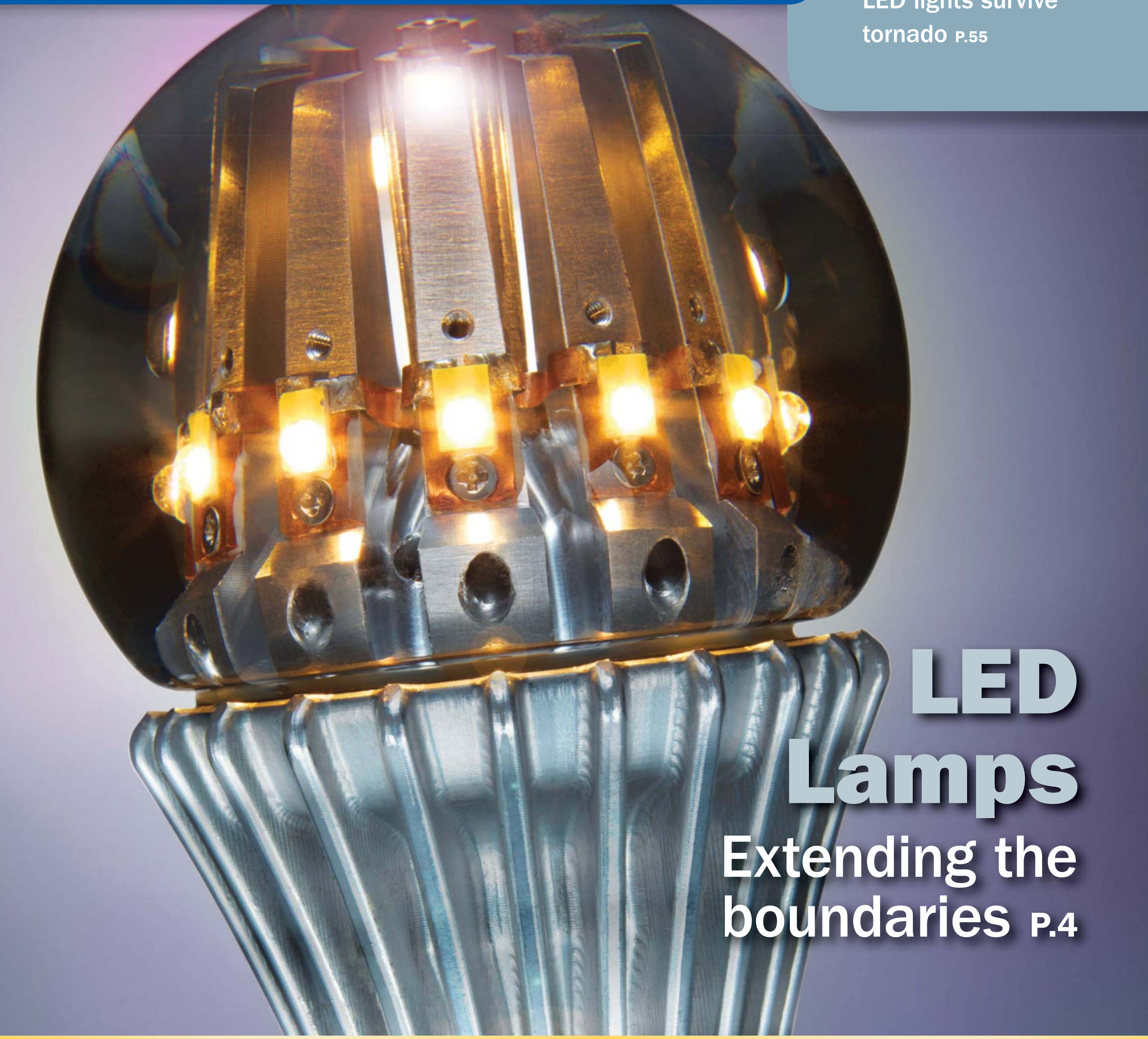

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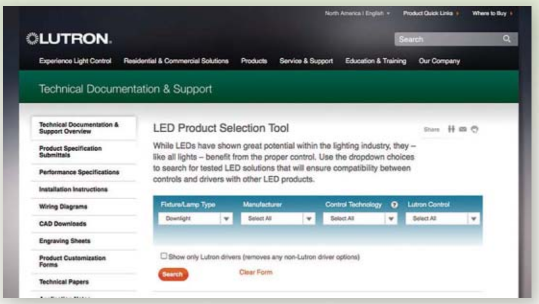

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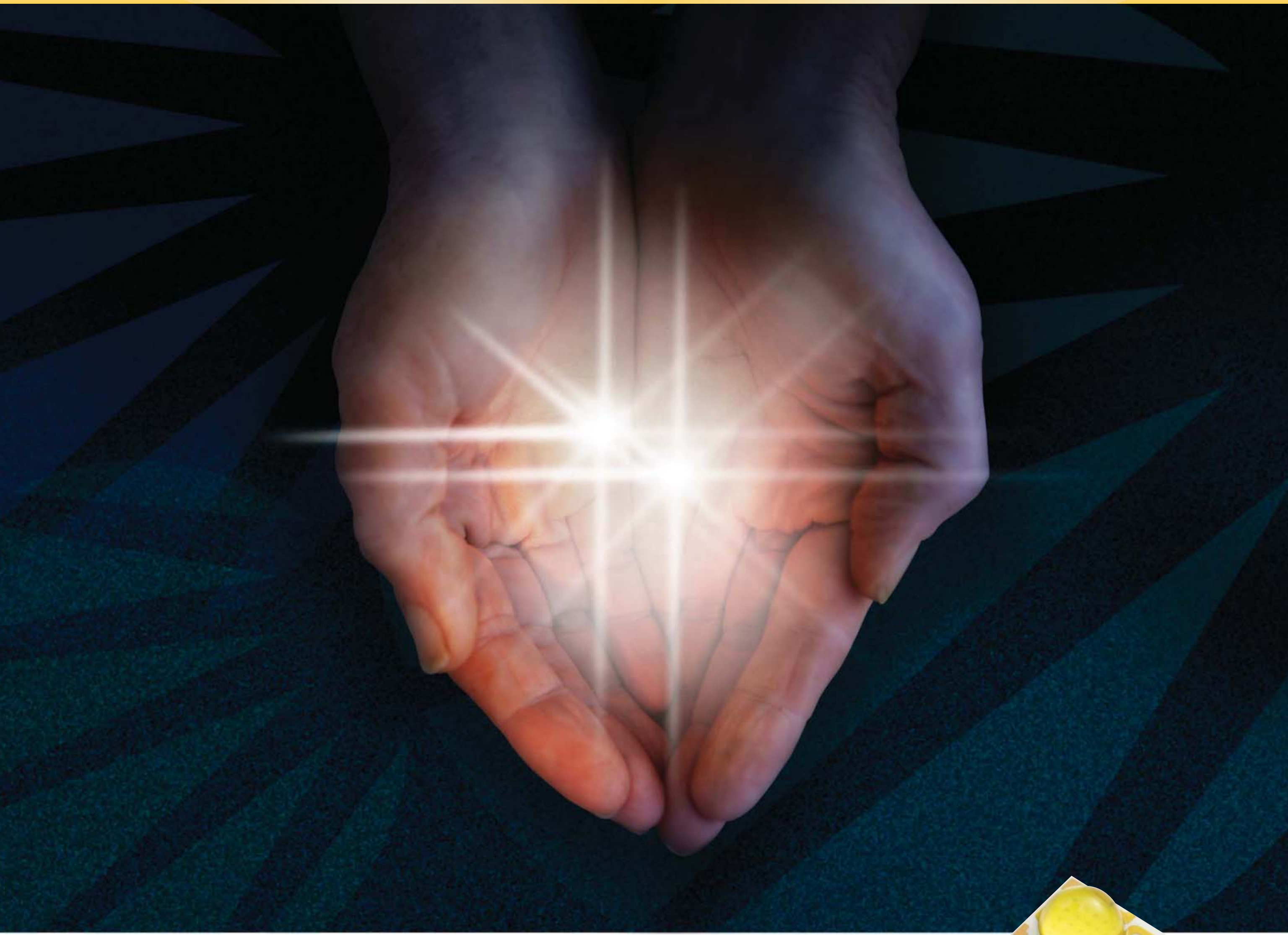

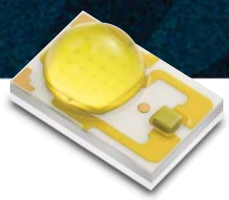

LEDs MAGAZINE ISSUE 43

june 2011

Cover Story

Switch Lighting's unique LED lamp design features LEDs mounted on metal fingers, inside a globe containing an inert liquid, creating a self-cooling environment. See page 16.

features

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commentary

New lamps for old, or brand new fixtures?

It's generally accepted that if you started with a blank sheet of paper, you wouldn't design LED lamps that look much like conventional incandescent or fluorescent lamps (either linear fluorescents or CFLs). This is because it's difficult to match the thermal and optical characteristics of LEDs with the form factors of conventional lamps and their sockets. Even so, there is a huge potential market for retrofit LED lamps that offer high performance at an acceptable price point, and companies are racing to stake their claim. Literally minutes ago I received an email entitled "First 100-watt-equivalent LED bulb" – see below for more details.

However, retrofit lamps are not the only answer. Cree, for example, recently announced a series of LED luminaires that are designed to replace the types of ceiling troffer fixture into which one would place a linear fluorescent lamp. As described on page 9, in Cree's luminaires a color-mixing chamber and reflector system produce the desired light output, while a room-side heat sink is incorporated as a design element.

Back to retrofit lamps. Yesterday I received a press release entitled "Philips to unveil the world's first LED replacement for the 75-watt light bulb." The EnduraLED A21 lamp consumes 17W, but will not be available until the fourth quarter of 2011 in the US. So perhaps the word "prototype" should have been included in Philips' press release. Several other companies might also disagree with the use of the words "world's first." The press release also says that the suggested retail price for consumers has not yet been finalized but is expected to be in the range of $40-45. Oddly, Philips did not give specifications except to say that the lamp has "been developed to meet or exceed Energy Star qualifications" for a 75W replacement i.e. 1100 lumens at 17W (65 lm/W), a color temperature of 2700K, a CRI of 80, and a 25,000-hr life.

In fact, Switch Lighting announced a 75W-replacement LED lamp several weeks ago (page 16). The design has some unusual features, namely outward-facing LEDs mounted on metal fingers, inside a globe filled with an inert liquid. This creates a so-called self-cooling environment inside the bulb, allowing maximum brightness with fewer LEDs, says the company. And just in time for Lightfair, Switch said it would show a 100-watt-equivalent A19 LED lamp that produces 1700 lm in neutral white, which is "the same beautiful white color as halogen track lighting," said Brett Sharenow, Switch's Chief Strategy Officer. He added that the company "will offer a warm-white version of the 100W-equivalent bulb in mid- to late-2012."

These announcements indicate the performance levels that we can expect to see in the shops over the next 1-2 years, although retail prices will need to hit the appropriate levels. The ongoing improvement in lamp performance is enabled in part by LED makers who continue to push the limits of LED efficacy, for example Cree's R&D result of 231 lm/W for a 4500K LED (page 10). Another factor is the development of more advanced LED fabrication processes, which are helping to improve yields and reduce costs, as our articles on pages 31 and 41 describe.

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DATE: June 22, 2011

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High-Voltage HB-LED Driver

www.ledsmagazine.com/whitepapers/6

Three-LED 300-mA MR16 Driver

www.ledsmagazine.com/whitepapers/5

Microsite:

LED Lighting Electronics Design

www.ledsmagazine.com/microsite/1

Web Exclusive Article:

How to interpret LED lamp data

To make the best lighting product choice, consumers must understand how to interpret lamp performance data. Jeanine Chrobak-Kando explains what kind of data is available, and how to use that data to make the best LED lighting choice.

www.ledsmagazine.com/features/8/4/1

FEATURED events

euroLED 2011
June 8-9, 2011
Ricoh Arena, Coventry, UK

LED Asia
June 9-12, 2011
Guangzhou, China

LED Lighting Taiwan 2011
June 14-16, 2011
Taipei, Taiwan

International LED EXPO 2011
June 21-24, 2011
KINTEX, Seoul, South Korea

SEMICON West 2011
July 12-14, 2011
San Francisco, CA, United States

The LED Show
July 26-27, 2011
Las Vegas, NV, United States

SPIE Optics + Photonics Exhibition
August 22-24, 2011
San Diego, CA, United States

OLEDs World Summit 2011
September 26-28, 2011
San Francisco, CA, United States

LED Japan / Strategies in Light
September 28-30, 2011
Yokohama, Japan

SIL Europe
October 4-6, 2011
Crowne Plaza Milan Linate, Milan, Italy

MORE: www.ledsmagazine.com/events

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news views

INTERIOR LIGHTING

LED lights illuminate paintings in London's National Gallery

© National Gallery, London

Over the next two years, the National Gallery, London, will install indoor LED lighting throughout its galleries, which will significantly reduce carbon emissions and improve the quality of light.

The gallery claims that it will be the first institution in the world to use LED lights in conjunction with a system that automatically adjusts external roof-light blinds according to the amount and angle of sunlight. This ensures that only diffused light is present in the galleries through UV-filtered roof-light glazing.

The new LED lighting system will slowly augment the natural light as needed, as opposed to the old system that can be distracting to visitors by going on and off abruptly. This is possible because LED lights can be dimmed with no change in color temperature, a major advantage compared to tungsten lamps says the gallery.

In the last three years, the National Gallery has explored ways to improve the quality, ease of control and efficiency of its picture lighting systems. During this period, improvements to LED lights have made them viable options.

After successful trials, the gallery has decided to install LED lights in all its galleries, reducing CO_2 emissions by 400 tonnes each year and reducing lighting energy consumption by 85%. The lifetime of the LED lamps is 25 times greater than that of the current tungsten lights, says the Gallery, leading to a significant reduction in maintenance costs. A further benefit of the new lighting system is that it does not produce any UV light, meaning that filters and the associated optical losses can be eliminated. ◄

MORE: www.ledsmagazine.com/news/8/4/13

INDOOR LIGHTING

Cree delivers LED alternative to linear fluorescent fixtures

Cree's CR family of LED-based fixtures are designed specifically as alternatives to high-end, architectural, fluorescent fixtures in applications such as offices and schools. The fixtures have 90- to 110-lm/W efficacy and will offer payback inside one year relative to T8 linear-fluorescent fixtures with comparable light output, says Cree.

The CR fixture design integrates a heat sink that is exposed to room air for cooling and that appears as an architectural design element of the fixture. Yellow and red LEDs radiate light upwards into a mixing chamber, and diffused white light is reflected on either side of the luminaire.

A range of sizes and options are available, including » page 10

PATENTS

Philips and Seoul swap LED patent lawsuits

An LED patent lawsuit has been filed by lighting company Philips and its LED subsidiary Philips Lumileds Lighting against Korea-based LED maker Seoul Semiconductor Company Ltd (SSC). The lawsuit, filed in March 2011 in the US District Court for the Central District of California, claims infringement of five Lumileds patents by a range of SSC products. Details of the patents and products can be found at www.ledsmagazine.com/news/8/5/4.

As well as the infringement claims, Philips is seeking a declaratory judgment that US patent no. 5,075,742, which is assigned to SSC, is invalid. Philips also wants a declaratory judgment that its own LED products don't infringe this same patent.

Philips was clearly worried that SSC might try to use the '742 patent against Lumileds, and said as much in its complaint. The patent was the » page 10

Philips from page 10 subject of an SSC press release in March 2009, in which the patent was described as being "fundamental" to InGaN-based LEDs. "Companies manufacturing or packaging blue, green, white or UV LEDs made from the semiconductor indium gallium nitride may be subject to patents owned by Seoul," said the press release (www.ledsmagazine.com/news/6/3/3).

Seoul files lawsuit against Philips

After LEDs Magazine wrote an article about the Philips lawsuit against SSC (see above), the Korean company issued a press release saying that it has initiated two actions against Philips. Asserting claims of patent infringement by Philips, the first action was filed in Germany in March and the second was filed in Korea in May.

Seoul also says that it intends to "vigorously defend the US patent infringement action brought by Philips" which it says is limited to "a handful of Seoul Semiconductor products" and that it "believes that its products do not infringe Philips' patents." No mention was made of Philips' assertion that the '742 patent should be declared invalid. ◂

MORE: www.ledsmagazine.com/news/8/5/10

LEDS

Cree reports 231 lm/W R&D LED

LED manufacturer Cree, Inc. has claimed a new R&D record for power-LED efficacy of 231 lm/W. The value was measured for a single-die component at 4500K. Standard room-temperature testing at 350 mA – i.e. pulsed testing rather than steady-state or "hot" testing – was used to achieve the results.

"It wasn't long ago when 200 lm/W was considered the theoretical maximum efficiency for a lighting-class LED. We broke that barrier in [February] 2010, and have now achieved 231 lm/W," said John Edmond, Cree co-founder and director of advanced optoelectronics. "The innovation from our labs is the foundation for our industry-leading XLamp LED family."

Cree says that the results came from an R&D component that features advanced aspects of the same technology used in the company's XLamp white LEDs. The same level of performance is not yet available in Cree's production LEDs. Cree says it believes higher-performance LEDs can enable new LED-based applications and drive down the solution cost of current LED-based designs. ◂

MORE: www.ledsmagazine.com/news/8/5/8

CONTROL

Google's Android controls LEDs

Google kicked off its annual Android developers' conference with a keynote presentation that featured a new home-automation initiative called Android@Home. A demonstration featured an Android phone controlling two prototype LED lamps from Lighting Science Group (LSG). The Android@Home technology will actually go far beyond lighting, with Google targeting control of all electrical devices in the home including appliances, HVAC systems, and entertainment products. It will also be compatible with the new Android music service.

The Android lighting demo included two table lamps equipped with the LSG prototype lamps, and the Android phone was also configured to control two stage lights.

David Henderson, chief development officer at LSG, said, "We look for this technology to revolutionize the home and commercial space for intelligent lighting systems, and LED lighting," adding that LSG would deliver production versions of the lamp by the end of the year.

One application suggested by Google was to set the alarm on an Android device, and have it gradually raise the light level in the room rather than ringing an alarm.

Henderson said that Android@Home would use wireless technology based on the IEEE 802.15.4 standard for wireless personal area networks (WPAN), overlaid with the 6LoWPAN (IPv6 over low-power WPAN) protocol. ◂

MORE: www.ledsmagazine.com/news/8/5/9

Cree from page 9 1 × 4-ft (CR14), 2 × 4-ft (CR24), and 2 × 2-ft (CR22) versions, with the choice of 3500K or 4000K color temperatures. The CRI is 90. The CR24, for example, comes in 2200-lm, 4000-lm, and 5000-lm models.

Cree's VP of Market Development Gary Trott said that, relative to the most-efficient fluorescents (often referred to as Super T8s), the CR products are 5 to 25% more efficient. Trott expects the price to the end user for the CR family fixtures to be in the $200 to $300 range, which he said is "in line with high-end architectural fluorescents."

Cree believes the payback projections for these products now make sense, although it's important to remember this is a replacement for the entire fluorescent troffer fixture, in contrast to LED tubes that fit into existing fixtures. "In some ways, replacing the entire fixture is easier than rewiring for a ballast and tube replacement and you don't have a UL problem," said Trott.

Cree already has some pilot customers that confirm the payback story. "We chose the Cree CR troffers because the payback calculation was clear," said Richard Michal, Facilities Engineer Planning Design and Construction, Butler University. "Seeing the CR troffers installed, they have an elegant aesthetic that produces an incredibly high-quality light. When you combine that with our predicted energy and maintenance savings, it was a no-brainer." ◂

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PATENTS

CAO Group files LED lawsuit

CAO Group, Inc. has filed an LED patent-infringement lawsuit against numerous rival LED-lighting manufacturers – GE Lighting, Inc., Osram Sylvania, Lighting Science Group Corp., Nexxus Lighting, Inc., Sharp Electronics Corporation, Toshiba International Corporation, Feit Electric Company, Inc., and Lights of America, Inc. – in the United States District Court for the District of Utah. The lawsuit asserts that LED light sources sold by these companies infringe CAO Group's patents. The company claims that the patents "protect innovations at the core of LED light source solutions." The patents listed are:

– US Patent No. 6,465,961 "Semiconductor light source using a heat sink with a plurality of panels."

– US Patent No. 6,634,770 "Light source using semiconductor devices mounted on a heat sink."

– US Patent No. 6,746,885 "Method for making a semiconductor light source."

By bringing the case, CAO Group, based in Salt Lake City, UT, says it "is protecting its investments in these innovations and its ongoing business and will pursue all available remedies in the lawsuit." ◂

MORE: www.ledsmagazine.com/news/8/5/13

FUNDING

Digital Lumens secures funding

Boston, MA-based Digital Lumens has established a new working-capital line of credit and received $10 million in Series-B venture funding to expand its operations. The company has now raised a total of $25 million in venture investments. Its Intelligent Lighting System includes networked LED-based luminaires that support adaptive controls and dimming, for high- and mid-bay industrial applications. The company states that its products already light millions of square feet of industrial space. ◂

MORE: www.ledsmagazine.com/news/8/4/6

LED RESEARCH

Rensselaer researchers boost green LED efficiency

Green LED efficiency has long lagged behind the capabilities of red and blue devices, but researchers at the Rensselaer Polytechnic Institute (RPI) have reported significant improvements in the lab. The team is forming nanoscale patterns on a sapphire substrate that boosts light extraction, internal efficiency, and light output.

Some early LED backlights for TVs utilized RGB LEDs, but the designs generally had to include two green LEDs for every red and blue one - adding significant expense and power consumption to the design. Likewise, RGB LEDs have been used in lighting but the need for extra green LEDs limits the applicability.

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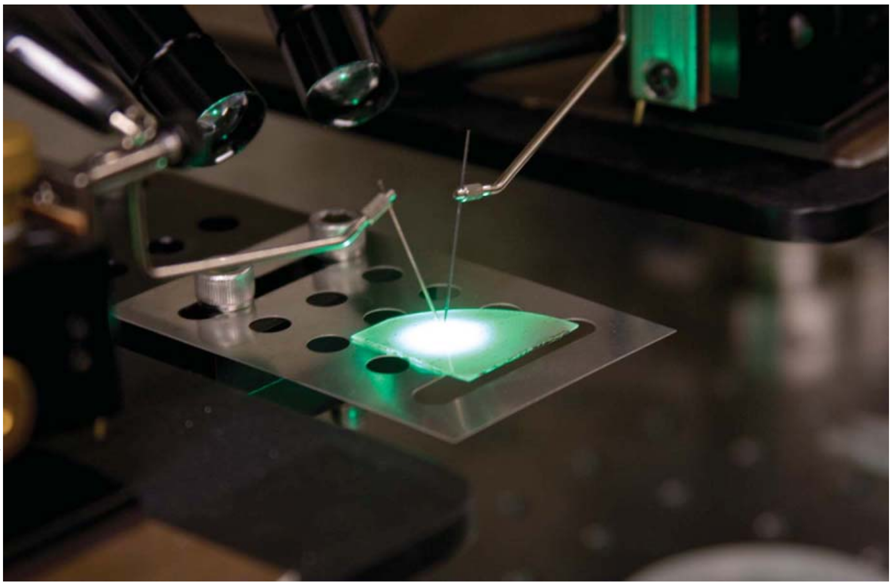


Photo: Rensselaer/Robbins

Green LED inefficiency stems from the charge-separation effect, in which electrons and holes are separated in the quantum-well region of the device. Light is generated when electrons combine with holes, but in green LEDs the separation results in fewer such combinations. Researchers have struggled for years with the problem.

Christian Wetzel, Professor of Physics and the Wellfleet Constellation Professor of Future Chips at RPI, is leading the green LED research team. The team used nanoscale patterning of the sapphire substrate and reported a doubling in the internal quantum efficiency of the LED. Moreover, the design enhances light extraction by a factor of 58%. The result could be brighter green LEDs, although it's unclear how soon the research could be applied in LED production. ◄

MORE: www.ledsmagazine.com/news/8/4/18

PATENTS

GT Solar sues ARC Energy

GT Solar International, Inc., a supplier of manufacturing equipment including furnaces for sapphire-crystal growth, has filed a lawsuit against a rival manufacturer. The lawsuit alleges misappropriation of trade secrets relating to sapphire crystallization processes and equipment, and was filed against Advanced RenewableEnergy Company, LLC (ARC Energy), as well as ARC Energy CEO Kedar Gupta and employee Chandra Khattak.

The complaint alleges that ARC Energy and the named individuals misappropriated trade secrets relating to GT Crystal Systems' technology for manufacturing sapphire, as a means of entering the sapphire crystal-growth equipment business.

In related news, Merrimack, NH-based GT Solar has announced a series of very large orders for sapphire-growth systems from Chinese and Taiwanese companies. One order for multiple growth furnaces totaling $218.9 million was received from Guizhou Haotian Optoelectronics Technology Co. Ltd (HTOT). "Our entrance into the LED market offers a new strategic growth opportunity for our company and Guiyang City as well as the Guizhou region of China," said Hao Xu, chairman of the board of Guizhou Industrial Investment Group. "Our new sapphire production facility will help to stimulate economic growth in the region and establish HTOT as a leading supplier of material to the LED industry.

Also, GT Solar received three new orders totaling $91 million from Alpha Crys-

news+views

tal Technology and Tera Xtal in Taiwan, and from the Lingyang Group in China. ◂

MORE: www.ledsmagazine.com/news/8/5/12

REPLACEMENT LAMPS

Switch unveils unique LED lamps

Switch Lighting, a ventured-funded, San Jose, CA-based startup, will launch a line of LED retrofit lamps at Lightfair based on a unique design. The LEDs are mounted facing outward on metal fingers and an inert liquid inside the globe cools the components, allowing for higher drive currents and brighter light from fewer components.

The 75W-replacement lamp pictured consumes 16W and uses only 10 LEDs to produce 1150 lm. It has a 2750K warm-white color temperature and a CRI of 85. The company will also demonstrate 60W and 40W replacements, and projects that the 60W lamps will retail in the $20 range, beginning in the 4th quarter of 2011.

Chief Strategy Officer Brett Sharenow believes the design will deliver superior radiant lighting to LED lamps currently on the market. Production lamps will use a frosted globe, distributing light in all directions. Sharenow said that the liquid inside the globe has an index of refraction that exactly matches the source and maximizes efficacy. The metal fingers upon which the LEDs are mounted, combined with the liquid, are designed to transfer heat to the globe and into the ambient environment. Switch calls the design "a self-cooling environment." ◂

MORE: www.ledsmagazine.com/news/8/4/17

PEOPLE

Former Color Kinetics CEO joins board of Lumenpulse

Lumenpulse Inc., a Montreal, Canada-based manufacturer of architectural LED-based lighting for commercial, institutional and urban environments, has appointed Bill Sims, former CEO of Color Kinetics, as a member of its board. In his seven-year tenure at Color Kinetics (CK), Sims oversaw the company's successful IPO, secondary offering and eventual sale to Philips (www.ledsmagazine.com/news/4/6/22) for $800 million in 2007.

Several other ex-CK employees are now senior staff members at Lumenpulse. These include senior VP and chief financial officer, David Johnson, who served as CFO at Color Kinetics; chief technology officer and director of engineering, Greg Campbell; and Brandon Siemion, executive VP of sales, the Americas.

Other ex-CK luminaries are now involved in new, growing companies in the LED lighting space.

Ihor Lys, one of CK's co-founders and the company's chief scientist until 2009, is the Technical Advisor to the board of directors of EcoSense Lighting. EcoSense founder and chairman George Mueller co-founded Color Kinetics with Lys in 1997.

Also, Fritz Morgan, CK's former chief technology officer, has joined Digital Lumens as chief product officer. Morgan previously worked with Bill Sims at Joule Unlimited Inc., where Sims is president and CEO. ◄

MORE: www.ledsmagazine.com/news/8/4/11

MODULES

Osram Opto unveils Brilliant-Mix

Osram Opto Semiconductors has unveiled an LED mixing concept named Brilliant-Mix, which combines white and amber LEDs to deliver warm-white light with high luminous efficacy (110 lm/W). The light-mixing approach uses EQ-White and Amber versions of Osram Opto's 1W-class Oslon SSL LEDs. These 3 x 3-mm LEDs can be closely clustered, making color-mixing easier and also improving the optical design at the system level.

With intelligent control, the Brilliant-Mix concept can cover a broad white-light spectrum from 2700 to 4000K. The typical value for the general color rendering index Ra is 92 at a color temperature of 2700K. ◄

MORE: www.ledsmagazine.com/news/8/5/11

LED LAMPS

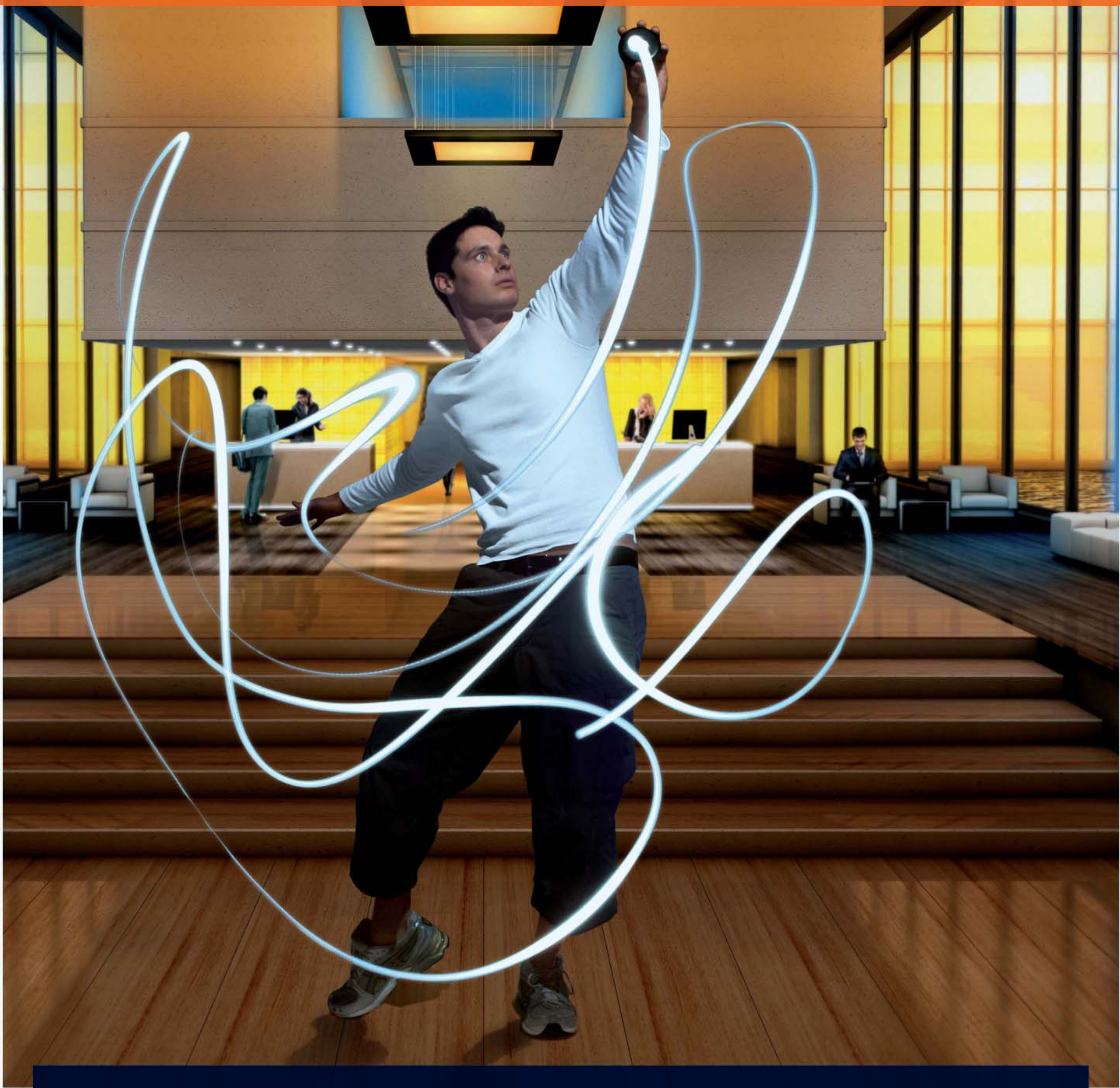
Acuity Brands launches Acculamp brand of LED lamps

Acuity Brands, Inc, a major US-based lighting manufacturer, has introduced its Acculamp product line, the company's first-ever series of LED lamps, which are aimed at commercial and institutional applications, including retail, hospitality and education. The LED-based Acculamp line is a result of the previously-announced business collaboration (www.ledsmagazine.com/press/31291) between Acuity Brands and Neonlite Electronic & Lighting (HK), Ltd. Neonlite is a leading lamp manufacturer, whose products are sold under the Megaman brand. The Acculamp products bear a very clear similarity to Megaman's LED lamps. Rather than using lenses, the lamps use reflectors to direct the light from the vertically-mounted LEDs.

The inaugural S-Series Acculamp product line includes LED versions of PAR16, PAR20, PAR30, PAR38, MR16 and AR111 lamps, in multiple color-temperatures (CCTs) and various beam patterns.

Acuity said that it had introduced Acculamp because "our customers demand a complete portfolio of performance-driven LED luminaire solutions, and this includes LED lamps." ◄

MORE: www.ledsmagazine.com/news/8/5/15



funding + programs

DOE updates SSL R&D plan, reports $50/klm LED retrofits

MAURY WRIGHT

The US Department of Energy (DOE) published a new Solid-State Lighting (SSL) R&D Multi-Year Program Plan (MYPP) in March of 2011 and revised the document in mid May. Among the highlights, the DOE reports that LED-based retrofit lamps have hit a $50/klm target two years ahead of the original DOE projections with "good-quality" 40W-equivalent lamps selling for $20 at big-box retailers. Packaged LED efficacy reached 96 lm/W for warm-white devices shipping in volume in 2010; the DOE is projecting 253 lm/W by 2020.

The MYPP serves to document the DOE's work in SSL, highlight recent advancements in R&D and commercially-available products, and chart the industry's progress toward future targets in lower-cost, more-efficient SSL.

The DOE reaffirmed the importance of SSL as both an energy-saving and economic-development engine, and has continued to aggressively invest in LED and OLED R&D. Fig. 1 shows how the agency has spread $120 million in investments as of March 2011. The funding covers a total of 47 projects awarded to small and large businesses, universities and research labs. The portfolio includes a mix of projects targeted at short- and long-term results.

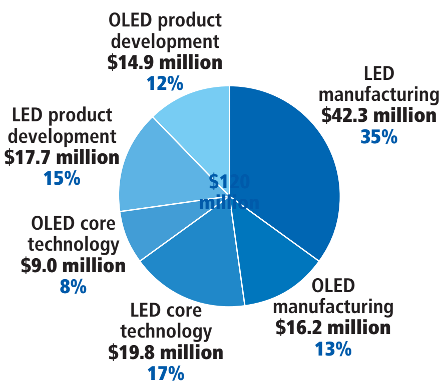


FIG. 1. To date, the DOE has invested $120 million in R&D projects in six different LED and OLED categories. Source: US DOE 2011 MYPP.

DOE-funded R&D achievements

The 2011 MYPP highlighted some R&D achievements of projects that have been funded since March 2010. The University of North Texas and the University of Texas, Dallas, have collaborated in OLED research on platinum-based phosphorescent emitters. The universities report a 65% gain in efficacy to 71 lm/W and better color stability relative to more commonly used iridium-based emitters.

Universal Display Corporation (UDC) also made several OLED advancements including development of a 51 lm/W prototype ceiling luminaire in conjunction with Armstrong World Industries and the Universities of Michigan and Southern California. UDC also reported 37,500 hours of life for an OLED pixel, and a prototype panel with 66 lm/W efficacy.

In the LED space, Philips Lumileds neared DOE 2010 performance targets by demonstrating cool-white Luxeon Rebel LEDs with an efficacy of 139 lm/W. The advance came via better chip-level electrical-injection efficiency, and improved optical extraction efficiency. In warm-white components, Cree hit 121 lm/W efficacy with its EZBright LED chip platform that was developed in part

Consortium for Solar Lighting founded

Sharp Electronics, Carmanah Technologies, Inovus Solar, and SolarOne Solutions have founded the Consortium for Solar Lighting (CSL) to accelerate the adoption of solar LED-based lighting through the development of universal specifications. This will help organizations evaluate and specify solar lighting for commercial-scale applications.

The founding members jointly said, "The team's development of universal specifications will contribute to greater end-user understanding and technology adoption. The goal is to improve and standardize communication of performance claims and [we are] eager to facilitate that effort."

The CSL organization intends to define common terminology and key metrics as its first milestone. A white paper entitled "Solar Lighting Recommended Practices: System Sizing – Preliminary Version" is planned for release in June.

The consortium has been careful to assert that it will not conflict with lighting-standards bodies such as CIE and IESNA. The CSL will focus on the energy side of the equation, pushing solar power in applications and geographic areas where it is a viable alternative to conventional grid-powered lighting.

The founding members cover a broad application and technology spectrum. Carmanah specializes in solar LED lighting for marine, aviation, traffic, and general off-grid applications. Inovus Solar is focused on solar-powered, LED-based systems for street, parking lot, and other area-lighting applications. SolarOne offers solar lighting systems as well as solar-powered systems for micro-utility applications such as water purification and wireless telecommunications. Sharp is a broad-line supplier of solar- and LED-lighting technologies that spans products from the component level to complete systems. ◄

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with DOE funding.

A number of DOE-funded projects focus on phosphor development both for use with blue emitters and in remote-phosphor lighting applications. Osram Sylvania demonstrated a remote-phosphor downlight that outputs 1439 lm with a fixture efficacy of 82 lm/W. Lightscape Materials is seeking to solve the thermal-quenching problem where phosphor efficiency degrades as LEDs generate heat. The company has demonstrated new red and green phosphors with quenching below 10% at 150°C – less than half of the quenching exhibited by conventional phosphors.

Metric	2010	2012	2015	2020
Cool white efficacy (lm/W)	134	176	224	258
Cool white price ($/klm)	13	6	2	1
Warm white efficacy (lm/W)	96	141	202	253
Warm white price ($/klm)	18	7.5	2.2	1

TABLE 1. DOE projections for packaged LED efficacy and price. Source: US DOE 2011 MYPP.

SSL energy savings

Several of the funded achievements feature efficacy improvements and therefore more energy savings, and of course that remains a key DOE mission. The new MYPP presented some data from the "Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications" report that the DOE released earlier this year. Cumulatively, SSL deployed across seven general-illumination categories in the US during 2010 saved 2.6 TWh in energy usage. The bulk of those savings came in outdoor applications. While applications such as A-lamp retrofits and 2x2-ft troffers contributed little to savings in 2010, SSL has just begun to penetrate those markets and the DOE expects significant growth in coming years.

The bad news is that LED retrofit lamps remain expensive relative to legacy light sources. The report noted that on a normalized-light-output basis, LED lamps are 100 times the cost of incandescent bulbs and five times the cost of dimmable compact fluorescent (CFL) lamps. Of course the report points out that lifetime cost is the key parameter and cited a specific example in the San Francisco Intercontinental Hotel where LED retrofit lamps delivered payback in 1.1 years (www.ledsmagazine.com/features/8/3/8). Residential application won't offer payback anywhere near as fast as that, but still the industry is progressing to lower prices, and better efficacy.

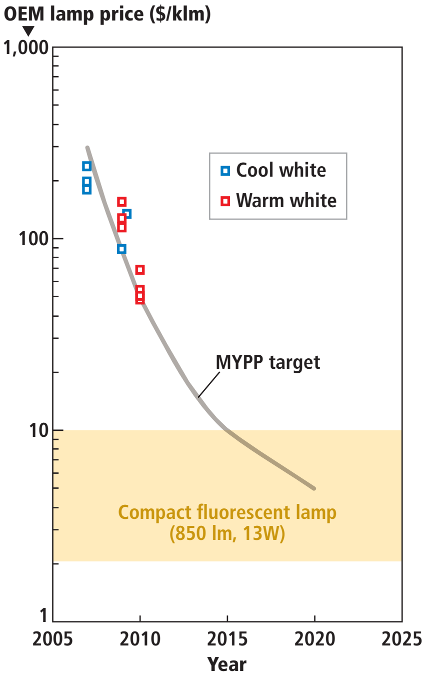

FIG 2. A comparison of OEM lamp prices on a logarithmic $/klm scale shows that LED lamps still have a way to go before matching the price of CFLs. Source: US DOE 2011 MYPP.

Fig. 2 depicts the DOE projections for LED retrofit lamps on a normalized logarithmic $/klm scale relative to a CFL reference. The top of the CFL range represents dimmable lamps while the bottom represents non-dimmable lamps. We are only four years from parity based on the latest projection. And as mentioned earlier, the SSL industry has been delivering $/klm advancements faster than earlier DOE projections.

The key to broader penetration of LED lighting across the spectrum of applications remains the combination of efficacy improve-

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ments and a drop in \$/klm. Table 1 summarizes the current status of packaged LEDs in these areas, with projections through 2020. It's interesting to note that the DOE continues to expect the gap to close in terms of efficiency of cool- and warm-white LEDs.

Milestone	Year	Target
Milestone 1	FY10	LED package: >140 lm/W cool white; >90 lm/W warm white; <\$13/klm (cool white)
Milestone 2	FY12	Luminaire: 100 lm/W; ~1000 lumens; 3500K; 80 CRI; 50,000 hrs
Milestone 3	FY15	LED package: ~\$2/klm (cool white)
Milestone 4	FY17	Luminaire: >3500 lumens (neutral white); <\$100; >140 lm/W
Milestone 5	FY20	<\$85 smart luminaire troffer

TABLE 2. DOE milestones for packaged LEDs and LED-based luminaires. Source: US DOE 2011 MYPP.

In a near-term outlook, it seems relatively certain that the 2012 efficacy goals are achievable. Companies such as Cree (www.ledsmagazine.com/news/8/5/8) and Phillips have demonstrated such performance in the lab. And LED makers have a pretty solid track record of delivering commercial products about 18 months after lab demonstrations.

Forward-looking priorities

The DOE will continue to fund SSL research, and to use its workshops and roundtables to engage industry experts in helping to define R&D priorities. The 2011 priorities include more research into core LED technology. The focus will include projects on droop and thermal sensitivity. Droop describes the phenomena where LED efficiency drops at higher drive currents. The core program will also include more phosphor research with a focus on better conversion and spectral efficiency.

In the area of LED product development, research will include investigation of alternative substrates, and new package architectures at the component level. At the luminaire level, product research includes luminaire and component reliability projects and novel luminaire designs that take advantage of unique LED properties.

Table 2 summarizes the milestones that the DOE uses to measure development in both core LED technology and products. The industry largely delivered on the DOE's 2010 goals, although the forward-looking roadmap is still an aggressive one. Just next year the DOE expects the industry to hit 100-lm/W fixture efficacy, and that's essentially where component efficacy stands today for warm-white LEDs.

OLED development and commercialization

The DOE continues to have almost as much interest in OLED technology as it does in LED technology despite the fact that the former hasn't yielded much in the way of commercial products. The interest is due to the inherent ability of OLED panels to serve as diffused light sources, and the potential of low-cost roll-to-roll manufacturing techniques. But the 2011 MYPP summarized some OLED findings, and said that big obstacles remain to OLED technology in general lighting.

There remain efficacy problems with OLED emitter technology. In general, manufacturers can't achieve sufficient light extraction in large panels. There are also encapsulation issues and transparent-conductor obstacles that remain to be solved.

Still, OLED prototype panels have demonstrated performance levels that could suit general illumination usage. ◄

California funds LED project

The California Energy Commission has awarded \$500,000 to Applied Materials for a research project to develop a more cost-effective way to manufacture LEDs. Funding comes from the Commission's Public Interest Energy Research (PIER) program. The project's total cost is just under \$8.72 million, of which Applied Materials will provide \$4.23 million. The company also received around \$3.99 million in Recovery Act funding from the US Department of Energy. Based in Santa Clara, CA, Applied Materials provides equipment, services and software to manufacturers of semiconductors and other products. The project is scheduled to be completed by July 2012. The company expects the project to create 1,600 jobs in California by 2015.

The project is working to reduce the costs of LEDs through improvements in manufacturing equipment and processes, in particular the key manufacturing step of metal-organic chemical vapor deposition (MOCVD). Improving the manufacturing process will decrease operating costs, increase LED efficiency, and reduce manufacturing waste since more LEDs will meet target specifications. Improving manufacturing efficiency means higher-quality LEDs would be fabricated at lower cost, helping to broaden the adoption of LEDs in the marketplace. ◂

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Michigan offers grants for advanced lighting demos

Michigan plans to fund 15-20 projects around the state that demonstrate the advantages of advanced lighting technologies. The Michigan Energy Office (MEO) will make available approximately $1 million from Recovery Act funds. The grants are designed to encourage highly-visible upgrades to more energy-efficient indoor and/or outdoor lighting using one of several possible technologies: LED-based solid-state lighting; induction lighting; and plasma lighting, also known as high-efficiency plasma (HEP) lighting.

The competitive application process, which closed May 26, is expected to result in 15-20 project grants ranging from $30,000 to $100,000. The MEO estimates that grants will start on August 1, 2011, and run through June 30, 2012. The MEDC lists several potential projects, including the replacement of street lighting, traffic and crosswalk lights, and parking structure/lot lighting, as well as interior lighting of public buildings. All incorporated cities, villages, townships and county jurisdictions in Michigan are eligible to apply. ◂

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DOE releases Gateway report on Walmart parking-lot lighting

The US Department of Energy (DOE) has published the final report from a demonstration conducted at a Walmart Supercenter in Leavenworth, Kansas, to evaluate the use of solid-state lighting (SSL) technology in a commercial parking-lot lighting application. LED luminaires were installed in a parking lot covering more than a half-million square feet. Since the demonstration was at a newly-constructed store, no baseline system existed, so comparisons were made to hypothetical designs using 1000W pulse-start metal-halide (PMH) lamps and 400W PMH lamps.

Compared to the 1000W PMH system, it was estimated that the LED system would achieve energy savings of 63%, with a 68% reduction in the minimum illuminance values. In comparison to the 400W PMH system, it was estimated that the LED system would achieve 44% percent energy savings while providing virtually the same minimum illuminance values.

When compared to the 1000W and 400W PMH systems, the LED system had 6.1- and 7.5-year paybacks, respectively, at Leavenworth's relatively-low electricity rate of $0.056/kWh. These paybacks were reduced to four and five years, respectively, when using the national electricity rate of $0.1022/kWh.

This installation represents the first use of the LED Parking Lot Performance Specification, developed by DOE's Commercial Building Energy Alliances, and demonstrates that the specification works in practice. ◂

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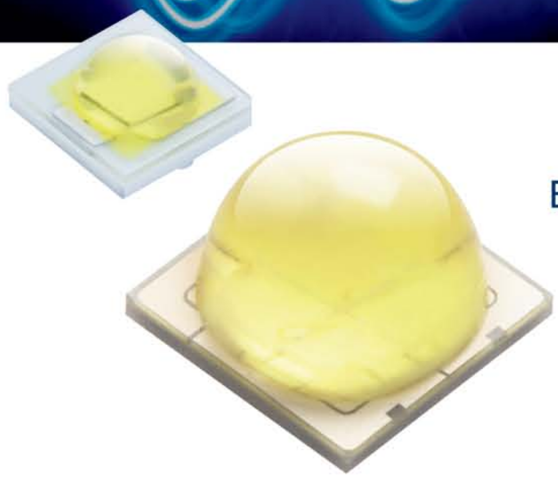

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Field trials of LED outdoor lighting demonstrate benefits to potential adopters

The LightSavers consortium of cities is undertaking an extensive and coordinated series of trials of LED outdoor lighting products, with a view to persuading the relevant authorities to adopt the technology, writes **PHILIP JESSUP**.

Innovation scholars like the late Everett Rogers teach us that acceptance of a new technology occurs when the potential adopter goes through a series of incremental steps that lead to the adopter's eventual persuasion. The process reaches a decisive stage when potential users see that a new technology offers superior performance compared with one they have used for some time, enough to outweigh any risks or additional costs that might be associated with something new.

It's no surprise, then, that potential adopters usually undertake field trials to test new products before they make up their minds. Once they have convinced themselves, early adopters also must decisively prove to their superiors that a change in technology or practice will benefit their organization as a whole. If it's not broke, why fix it?


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Engineers contracted by TfL (Transport for London) measure lighting levels of LED street lighting on a test site on Blackfriars Road, Southwark, central London.

In 13 mostly large cities located in seven countries – ranging from London, UK and New York, US to Tianjin, China and Kolkata, India – municipal lighting asset managers are putting market transformation theory into practice. Under the guidance of The Climate Group's global LED program and with the sponsorship of HSBC bank, the LightSavers consortium of cities is engaged in an unprecedented coordinated global trial of LED street-lighting and parking area/garage products.

Three LightSavers cities have accumulated up to 6,500 hours each of operational experience and are now reaching the decisive acceptance stage.

New York City

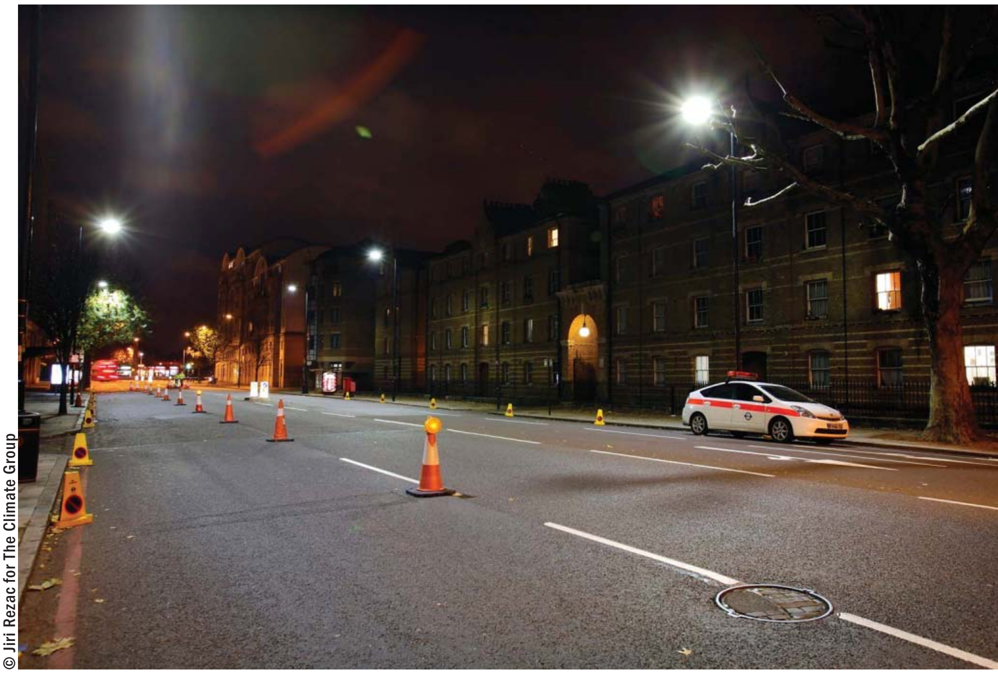
In late summer/fall 2009, the New York City Department of Transportation (DOT) began trials of LED products in two locations. Five LED post-top heritage products replaced metal-halide lamps on pedestrian walkways in historic Central Park. Also, four LED street-light luminaires replaced high-pressure sodium (HPS) cobra-head luminaires along FDR Drive, an urban expressway on Manhattan's east side. DOT staff have compiled over a year of illuminance data collected on a monthly basis, along with measurements of energy savings, color temperature, and ambient temperature.

The US DOE Gateway program has also taken its own measurements at each site. They are testing luminaires from the FDR Drive trial in a laboratory to quantify possible lumen depreciation due to dirt on the luminaires. Final reports from both the DOT and DOE data-gathering efforts should be released in summer 2011.

PHILIP JESSUP *is the Director of International Lighting for The Climate Group (www.theclimategroup.org), a global NGO working internationally with government and business leaders to advance the smart policies, technologies and finance needed to cut global emissions and unlock a clean industrial revolution.*

Interim results are very encouraging. They show that among the nine LED products tested, several have exhibited excellent performance over the past year, matching or approaching the illuminance of the baseline while delivering significant energy savings, very good lumen maintenance, and negligible color (CCT) degradation.

The DOT is sold! Staff is readying a tender to replace all 1,600 heritage lamps in Central Park. The department has received a grant for this purpose, so financing won't be necessary. Meanwhile, various options for upgrading the City's 25,000 arterial street lights with LED luminaires are being explored.



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LED street-lighting test site at Blackfriars Road, Southwark, central London. LED lamps, combined with smart controls, can cut CO_2 emissions by 50-70%. Lighting accounts for nearly 10% of global CO_2 emissions, more than cars worldwide.

Toronto, Canada

The Toronto Atmospheric Fund (TAF) has been working with another City of Toronto agency, the Toronto Community Housing Corporation, to test a LED luminaire product in two housing-residence garages. T8 lamps were tested alongside the LED products. Both products incorporated adaptive controls that increase light output when there is movement nearby, allowing the baseline light output to be set below previous practice.

The products have operated 24/7 over 6,500 hours and nine months – the longest operational time among the LightSavers trials to date. Performance has been convincing, e.g. energy savings of 70%, excellent lumen maintenance over the period, and strong public acceptance. Tellingly, social-housing residents reported in surveys that they thought the LED and T8 lighting provided higher light levels than the baseline HPS fixtures, despite a designed reduction in illuminance levels of 20-30%. Residents liked the adaptive controls as well – illumination increases when residents enter and move about the garage, improving safety.

Despite their higher cost, housing officials appear to favor the LED luminaires, due to strong public endorsement and the likelihood that residents won't be calling their local councilors to complain about lights burning out in their local garage. TAF's final report on the trials is now available at: www.lightsavers.ca.

TAF and its partners are now conducting further engineering and financial studies to replace the existing lighting in 30 garages using about 3,000 luminaires. TAF is also creating a procurement consortium with local hospitals and other public agencies, to jointly tender LED products to further reduce prices.

Sydney, Australia

Even before the City of Sydney joined the LightSavers consortium, city staff had already mounted four trials testing a variety of LED street-lighting products. A second phase of trials integrating smart controls, organized with the help of The Climate Group, began in 2010. This set of trials uses the LightSavers monitoring protocol, which facilitates performance comparisons with other cities' trial results. In this second phase, the city also commissioned a public opinion survey of the LED lights under trial.

As a result of compelling performance results emerging from the trials, the city of Sydney's staff and local elected officials have become sold on LED technology, and are now looking to replace all of the 8,559 street and park lights under their operation. The overwhelmingly positive results of the public opinion survey were instrumental in convincing elected councilors to take the plunge.

The city's tender seeks replacement of conventional lights with LED technology over three years. Winning bidders will be expected to deliver the city a minimum saving of 40% and greenhouse-gas reductions. Meanwhile, city officials are exploring various financing options.

Summary

Well-conceived, rigorous LED trials are proving decisive in three LightSavers cities as product evaluations indicate the new technology performs well, meeting or exceeding the expectations of potential adopters. Public acceptance, as measured by surveys and opinion polls, has also built political support in two cities, thus contributing to the acceptance of LED technology by lighting asset managers.

The higher capital cost of LEDs, however, remains a significant barrier. Apart from NYC's Central Park scale-up, which is financially subsidized, the three remaining cities still need to identify pragmatic financial solutions that will capitalize on the lower operating and maintenance costs of LED technology over the lifetime of a replacement program.

LED industry requires versatile equipment to suit different needs

Collaboration with equipment suppliers can help LED manufacturers to get equipment specifically designed or adapted for their needs, and can also result in shorter development cycles for new products and process flows, according to **THOMAS UHRMANN** and **THORSTEN MATTHIAS**.

Comparing the LED industry with the IC industry shows many parallels, but also many differences. Both industries are driven by the need to increase device performance while lowering the overall manufacturing cost. While the IC industry follows Moore's law by scaling mainly the transistor size, which results in increased integration density and performance, the LED industry does not have the possibility of scaling. However, increasing the overall LED efficiency enables the reduction of real estate required to produce the same lumen output. Since LED makers are at very different efficiency numbers right now, strong competition is present. One result is that manufacturers are conservative with high-end equipment spending until they settle on the applications on which they will focus.

Another difference between the LED and IC industries is that the LED industry currently has little standardization. In this sense, the LED industry is very comparable with the IC industry many years ago. A key reason for the lack in standardization is the vast variety of applications for LEDs across different market segments. To compete efficiently, LED manufacturers rely on highly-customizable and proprietary process flows for manufacturing.

More recently, the strong growth in the LED market has triggered the entry of major IC manufacturers into the LED industry. Therefore, differences between the two industries are expected to blur. The transfer of manufacturing and statistical methodology from the IC industry is adding considerable value for the LED manufacturers. Indeed, changes are needed to adapt IC-specific tools, such as statistical process control, to the LED industry, where the parameter range is entirely different, but the toolbox is already present.

THOMAS UHRMANN *is Business Development Manager and* THORSTEN MATTHIAS *is Business Development Director with EV Group (www.evgroup.com), an equipment manufacturer based in St. Florian, Austria.*

Customized process flows

The fast market pace and the lack of standardized process flows have major implications for LED manufacturers and equipment suppliers alike. As already mentioned, the main way in which LED manufacturers achieve competitiveness is via highly-customizable process flows to fit all kinds of LED applications. LED manufacturers often use very different process flows for different applications and LED designs. This in turn means that standardization and optimization of individual processes is difficult.

For the equipment manufacturers, tools must be highly flexible and customizable to satisfy the individual customer needs. For example, different LED chip designs – such as lateral, vertical, flip-chip or thin-film-flip-chip designs – demand differences in the manufacturing process flow and hence in equipment. Depending on the LED design, different substrate sizes or even different substrate materials may be used that challenge the equipment in an entirely different way. Therefore, a close collaboration between LED manufacturers and equipment suppliers is essential to address individual manufacturing challenges.

The battle for improved LED efficiency is mainly fought between the high-end LED manufacturers that are investing considerable effort in research and development. On the other side stand newly-established companies that have just entered the market in the last couple of years. Gaining ground in this battle is essential if the newcomers want to remain competitive. A comparatively small percentage increase in overall LED efficiency can considerably reduce the required chip area for a certain amount of lumens. This is achieved by increasing the extraction effi-

FIG. 1. EVG 560HBL fully-automated wafer bonder dedicated for HB-LED manufacturing.

ciency as well as improving the current injection and internal quantum efficiency. The two latter aspects are seen as an essential step for low-cost, low-droop, high-efficiency luminaires for general lighting.

Collaboration and standards

Many different routes can be taken to improve the overall LED efficiency. However, limited resources restrict the number of routes that can be evaluated. Equipment suppliers – mainly for front-end, wafer-level equipment – are seen increasingly as development partners for the exploration of novel LED manufacturing solutions. The experience of equipment suppliers, and knowledge gained in other markets, can add considerable value for LED manufacturers, significantly shortening their development cycles.

One example of collaborative development is the NIL-COM Consortium. Companies and research organizations throughout the nanoimprint lithography (NIL) supply chain are collaborating to enhance the whole value-chain needed for the cost-effective production of photonic crystals. Stimulating the supply chain – for individual processes or for the overall LED process flow – could accelerate improvements in cost reduction and efficiency for many LED manufacturers.

FIG. 2. EVG 620HBL fully-automated mask aligner dedicated for HB-LED manufacturing.

For the IC industry, SEMI standards create standardization of manufacturing equipment, in the sense that equipment requirements are similar or equal among different IC manufacturers. For the LED industry this is not the case. While high-volume manufacturers of HB-LEDs rely mostly on fully-automated solutions, small- and medium-scale manufacturers use mainly manual equipment.

To satisfy the needs of all sizes of manufacturers, equipment suppliers need to have a very complete portfolio, ranging from manual to semi-automated to fully-automated, high-volume equipment. Therefore, highly versatile and universal equipment platforms are needed to suit the varying demands of LED manufacturers. In order to fulfill this demand, field-proven and highly-developed equipment from the IC industry can be used as a basis on which to develop special features that are LED specific and manufacturer specific.

Optical lithography

Optical lithography is the preferred patterning technology for high-brightness LEDs, where minimum feature sizes are in a range of 5 µm. From a cost-of-ownership perspective, full-field lithography with mask aligners is preferred over competitive patterning technologies, such as projection steppers, where capital expenditure is high and throughput is low.

Starting with EV Group's well-developed and field-proven EVG 620 mask aligner – used in IC packaging, MEMS and compound-semiconductor manufacturing – different LED-specific features have been implemented. One of the obstacles for GaN-based LED manufacturing on sapphire is the materials' optical transparency. Etching steps, down to the buried n-GaN layers, are therefore optically hard to resolve. The development of special optics to align such low-contrast structures is essential. Furthermore, LED wafers are highly bowed after the epitaxial growth process. A special wafer-chuck design guarantees efficient flattening of sapphire wafers and hence a constant print-gap between LED wafer and photomask. In this way, non-contact processing with superior overlay accuracy of multiple masks results in a high yield. The EVG 620HBL (Fig. 2) delivers highest-in-class throughput of up to 165 wafers per hour in aligned mode (220 wafers per hour in first-print) and autonomous operation of 125 wafers for low cost-of-ownership.

Wafer bonding and NIL

Wafer bonding is most commonly used for active-layer transfer. In this process, the growth substrate – GaAs for AlInGaP-based and sapphire for InGaN-based LEDs – is substituted with another carrier that offers higher thermal conductivity and improved optical properties. With the EVG 560HBL (Fig. 1), EV Group has introduced the first wafer-bonding equipment dedicated solely to the LED market. The tool is designed for high yield enabled by optimized pressure and temperature distribution, combined with a throughput of up to 176 bonds/hour (2-inch wafer equivalent) using multi-substrate bonding. Sapphire wafers often show high thickness variation. The EVG tool's proprietary thickness-compensation feature ensures homogenous pressure distribution over each individual wafer pair for optimum performance.

Nano-imprint lithography (NIL) can be applied for the simultaneous generation of structures ranging in size from microns down to a few nanometers. Such small features are used in LEDs for improved light extraction, either via photonic-crystal structures, or nano-patterned sapphire substrates. Nano-patterned sapphire substrates efficiently reduce the density of threading dislocations, showing promising results that could close the so-called green gap with highly-efficient InGaN LEDs. Developments in stamp material and manufacturing technology enable a cost-effective and high-throughput imprinting process on the wafer scale. Soft stamps are generally used for LED applications to conform to surface roughness and spikes stemming from the epitaxial process.

Future developments

Looking to the future, close collaboration of LED manufacturers and equipment suppliers will become more essential. On the one hand, collaboration helps LED manufacturers to get equipment specifically designed or adapted for their needs. On the other hand, equipment suppliers can be valuable development partners for novel LED technologies, efficiently shortening development cycles for new products and process flows. In addition, equipment developers are preparing right now for increased fab automation as well as increasing wafer sizes. Economies of scale and automated, single-wafer processing are expected to further enhance yields and hence reduce manufacturing costs.

Serving such a rapidly-changing market, where different technologies are still seeking pole position, requires equipment manufacturers to stay flexible in order to meet the different requirements and specifications of LED manufacturers.

Interchangeable lenses all light distribution in archite

In architectural lighting, interchangeable tertiary lenses can offer a significant advantage over other optical systems, as **THOMAS SCHIELKE** explains.

Discussions concerning the efficiency of LED lighting largely revolve around the high luminous efficacy of the semiconductor light sources. As a result, the potential of the light-guidance system is often pushed into the background. However, while the development of increasingly more efficient LEDs occupies the research laboratories of the major corporations in the electronics industry, the optimisation of LED technology gives luminaire manufacturers the chance to optimise their own lighting engineering and to provide users with definite advantages in terms of lighting quality, flexibility and economic efficiency.

The optical systems for LED lighting products are very different from conventional luminaires with reflector technology. Because transmission with lenses is more efficient than reflection with reflectors, LED luminaires fitted with the appropriate lens systems deliver a better light output ratio. In architectural lighting, interchangeable Spherolit lenses offer the big advantage that differentiated light distributions can be obtained. Alternative lenses can be exchanged simply to suit altered lighting tasks with one and the same luminaire.

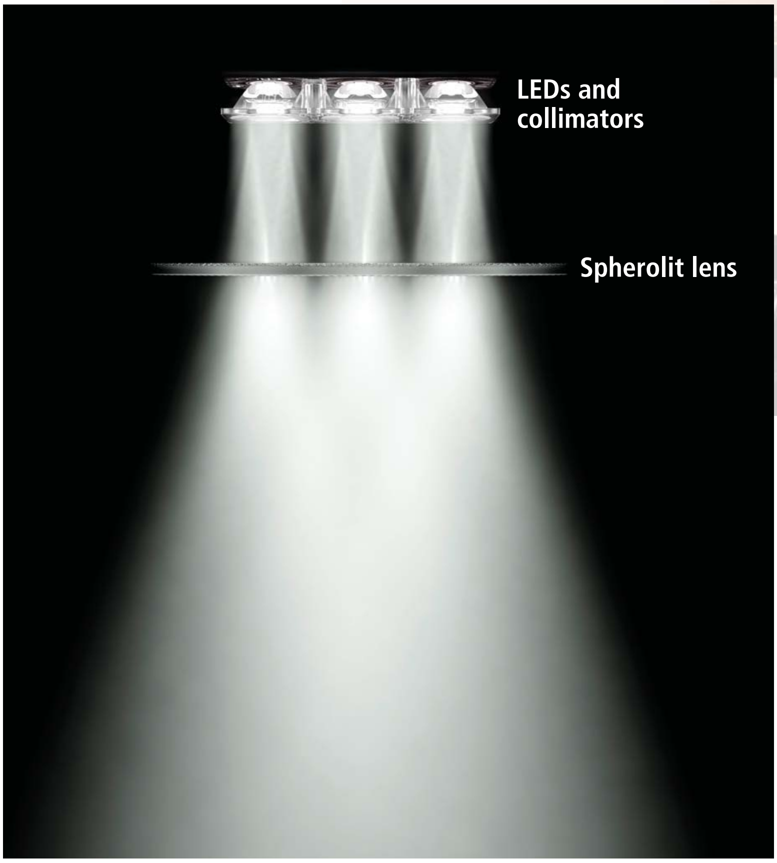

FIG. 1. The light
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Spherolit technology

As described in this article, lighting manufacturer Erco has developed Spherolit lenses for LED optical systems.

Spherolit technology is based on dividing up a large lens surface into individual, three-dimensionally domed facets that control the light using refraction. By individually shaping each "spherolite" facet, the characteristics of the lens can be extensively controlled. Depending on the curvature of each individual facet, the parallel incident light is dispersed to a greater or lesser extent. This results in different lenses that, for the same basic geometry, can have different beam angles ranging

THOMAS SCHIELKE *is a lighting designer with ERCO (www.erco.com), a lighting manufacturer based in Lüdenscheid, Germany.*

FIG. 2. Differentiated lighting design requires specific light distributions: accentuated lighting with different beam angles for small and large objects with various lighting distances, "oval flood" for large, long items and wallwashers for uniform illumination of vertical surfaces.

low for differentiated ctural lighting

is guided by three elements: the system with the lens directly on e secondary optical system in the ator to align the rays of light into and the tertiary optical system in pherolit lens. The choice of tertiary the light distribution and depends pplication.

from "narrow spot" to "wide flood." Made of optical polymer, the lenses are extremely high precision components and place exacting demands on tool making and on manufacturing via the injection-molding process.

Photometric systems

The quality of an optical system has a major influence on the overall efficiency of an LED luminaire. The combination of an LED lens, collimator and Spherolit lens can provide a very high performance and flexible system in architectural lighting (Figs. 1 & 3).

A collimator, made of an optical polymer and acting as a secondary lens, forms the link in the chain between the LED lens on the printed circuit board, as the primary lens, and the interchangeable Sphe-

rolit lenses as the tertiary lenses. The collimator aligns the light of the LED chip, with its hemispherical light distribution, into a parallel beam so that the required light distribution can then be formed by the replaceable tertiary lens.

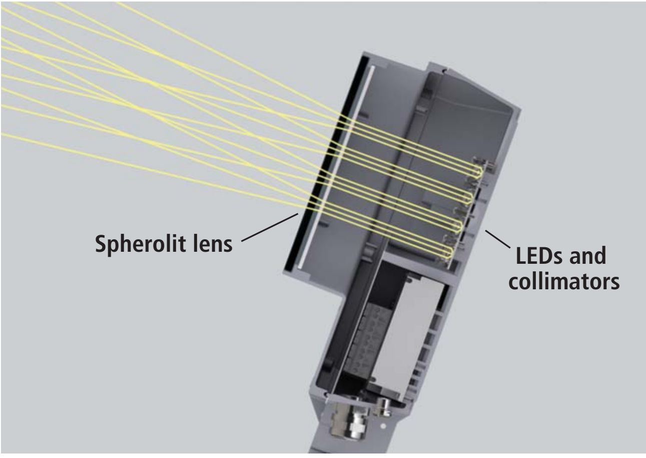

FIG. 3. Cross-section of an LED-based luminaire that incorporates a Spherolit lens to provide a directed light distribution.

This approach offers the practical advantage that in situations where the use of the lighting is always changing, such as in exhibitions or in showrooms, the light distribution can be altered to suit the lighting task thanks to an interchangeable system. By exchanging the tertiary lens from one that gives a narrow beam for accent lighting to one with a wall-washer characteristic for vertical ambient lighting, it is an easy matter to modify the lighting concept and the atmosphere in the room.

Clip-mounted Spherolit lenses allow both lighting professionals and ordinary users alike to alter the light distribution. The sensitive interface between the LED chip and the collimator can be precisely and cleanly fitted in the factory, while the easy exchangeability of the Spherolit lenses gives the user the benefit of adjustability in actual usage situations.

Collimator as secondary lens

Depending on the design of the collimator, the rays of light are formed into a parallel beam via total reflection at the edge surfaces or even in combination with a middle lens section. The advantage of collimators, which function solely by total internal reflection, lies in their high efficiency. In terms of production engineering, the normal injection-molding process is faced with the challenge of having to ensure that component thicknesses are as uniform as possible. This is to avoid what are known as sink marks, which occur as the component cools down, and could otherwise impair the guidance of the rays from the LED.

In contrast to normally-used collimators, therefore, the middle lens section in this case is replaced by a Fresnel lens of reduced component thickness in order to simplify the injection molding process (Fig. 4).

However, the very-narrow-beam light distribution of LEDs presents a particular challenge. According to the law of conservation of geometrical optics, a relatively large emission surface is required for the very small luminous surface of the LED chips.

To enable a normal injection molding process to be used for this collimator too, a special variant has been developed that uses double total internal reflection to allow a relatively uniform component thickness (Fig. 5). This principle also enables a more efficient light guidance for very narrow beam angles using readily obtainable systems with a combination of reflector and lens.

Pins positioned on the collimator facilitate precise and fast installation on the PCB using screws or clips. The screwed-on attachment to the heat sink also forms a thermal connection, providing heat management for the LED chips.

Spherolit lens as tertiary lens

The actual light distribution, which may be narrow beam for accent lighting or wide beam for flood-type lighting for instance, is determined using Spherolit lenses as tertiary optical systems (Fig. 6). Axially-symmetrical Spherolit geometries can produce oval beams, allowing elongated sculptures or tables to be illuminated with just one luminaire, whereas asymmetric Spherolit forms can be used for uniform wall-washing. The Spherolit geometries have been designed to give beams that are particularly uniform and without striations, while having clear, slightly softened edges. To help the user identify these lenses, which often look very similar, the edges of the Spherolit lenses are labelled with the name of their particular characteristic.

Compared to systems that only use one collimator, this approach using collimators and tertiary lenses does produce losses due to reflections, albeit very low losses.

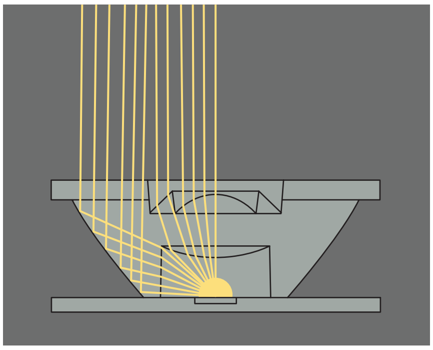

FIG. 4. To enable a simple injection molding process to be used for the manufacture of the collimator, the lens in the middle is replaced by a Fresnel lens with a thin component depth. The component thicknesses are therefore quite uniform and this avoids what's known as sink marks occurring as the component cools down.

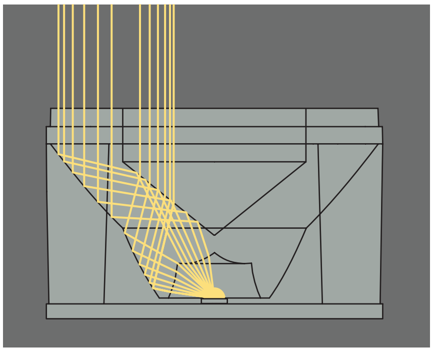

FIG. 5. The effect of the collimator for producing a very narrow beam light distribution is based on the optical principle of total internal reflection and double total internal reflection. This contributes to the high efficiency of the photometric system.


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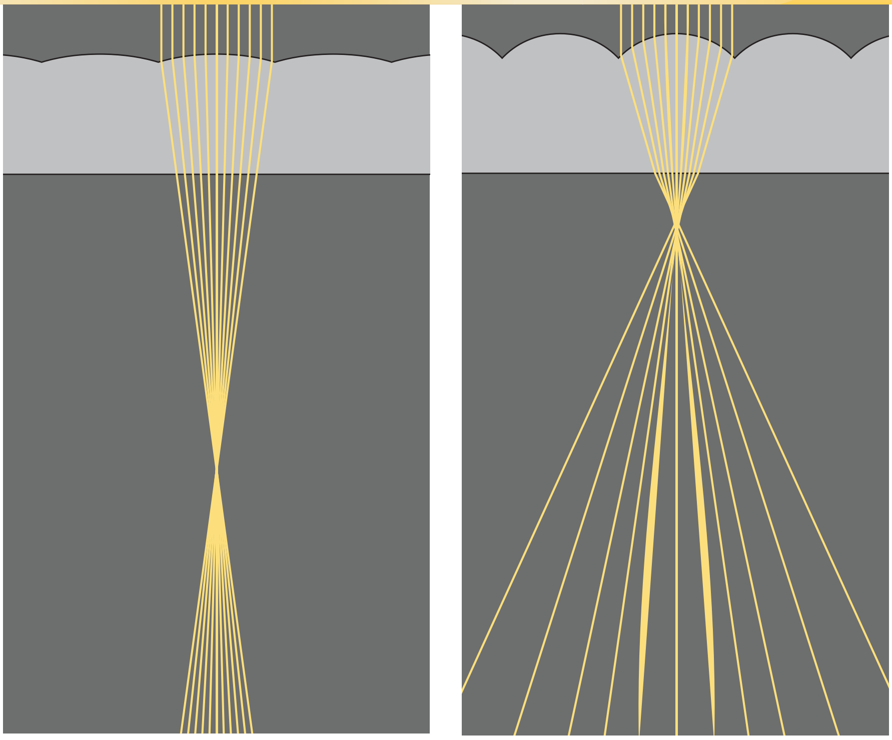

FIG. 6. (left) The "spot" Spherolit lens has flat spherolites and therefore produces low dispersion for a narrow beam angle. (right) The curvature of the spherolites is the most pronounced with the "wide flood" Spherolit lens. The wide dispersion produces a beam of light with a large beam angle.

However, this is far outweighed by the benefits in terms of increased flexibility in use. To obtain a different light distribution, it is not necessary to have another luminaire, but just to use a different Spherolit lens. Furthermore, the more complex optical systems such as "oval flood" or "wall wash" cannot be achieved using pure collimator technology.

Efficiency of Spherolit lenses

Conventional point-light sources such as low-voltage halogen lamps or high-pressure discharge lamps emit their light in a solid angle of virtually 360°, whereas LEDs, which are directed by nature, emit their light in a solid angle of <180°. This means that losses due to spill light or light emitted towards the lamp holder are avoided.

Furthermore, since transmission via lenses is more efficient than reflection via reflectors, the use of a lens results in a better light output ratio, which in turn has an effect on the resultant luminous flux from the luminaire.

Thus, for instance, LED wall washers with Spherolit lenses have a light output ratio (LOR) of approximately 80%, which is about twice that of lens wall-washers with conventional lamps, reflectors and wall-washer attachments (LOR approx. 40%). They even out-perform wall washers with Spherolit reflector technology (LOR approx. 60%).

The efficiency of spotlights can be compared by keeping the beam angle constant and recording the illuminance obtained at the center of the beam relative to the power expended. Here too, LED spotlights with Spherolit lenses (approx. 70 lm/W) again out-perform spotlights with Spherolit reflector technology (approx. 50 lm/W).

Unlike with conventional lamps, such as high-pressure discharge lamps, it is expected that the future will bring further considerable increases in the luminous efficiency of LEDs. Every efficiency increase in the optical system will therefore act as a multiplication factor and make an even more significant difference.

For project-related simulations and calculations, all luminaires are measured in the lighting laboratory and are available as virtual luminaires complete with the relevant photometric data and 3D geometry.

Conclusion

The lighting engineering system of LED lens, collimator and Spherolit lens provides lighting designers with a flexible toolbox for highly varied lighting tasks. The wide selection of photometric characteristics, consisting of point-symmetrical, axially symmetrical and asymmetrical, lays the foundation for qualitative lighting design and efficient visual comfort. For this technology to develop, it was essential for various departments to be brought together at one location: development (with its capabilities in lighting simulation), tool making and plastics processing, complete with all their technical expertise of the manufacturing process. This cooperation has enabled the system design to be improved in a holistic manner and has allowed the efficiency of the optical system to be optimised by fine-tuning.


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LED FABRICATION

Automated defect-data analysis allows comprehensive yield management in LED manufacturing

Automated, systematic analysis of defects during LED wafer manufacturing should reduce the time needed to identify and resolve the underlying problems, according to authors from **PHILIPS LUMILEDS** and **KLA-TENCOR.**

The LED manufacturing industry is facing a number of production challenges, driven by the evolution of higher-power and higher-performance LED devices along with the emergence of new high-end, high-volume applications such as solid-state lighting. At the same time, the parameters for acceptable devices are becoming more stringent, and the market is imposing higher production-volume requirements and price constraints.

Taken together, these driving forces are raising the bar significantly with regard to yield management in LED manufacturing. The current approach taken by LED manufacturers relies heavily on manual gathering, review and analysis of defect/yield data. As LED manufacturers see increased demand for their products and more competition in the market, the need for an automated, systematic defect-analysis methodology has become more apparent.

To address these escalating requirements, leading LED manufacturers such as Philips Lumileds Lighting are pioneering new automated-inspection methods based on technologies such as those from KLA-Tencor that have already proven successful through multi-generation deployments in the semiconductor industry.

This article examines an automated software solution for inline analysis of KLA-Tencor's ICOS WI-Series defect-inspection data using the same company's Klarity LED yield-analysis solution. The objective is to use the graphical charting and quantitative analysis capabilities of Klarity LED to reveal a clearer understanding of defect trends, improve the analysis capabilities, and reduce the time needed to identify and resolve defect issues.

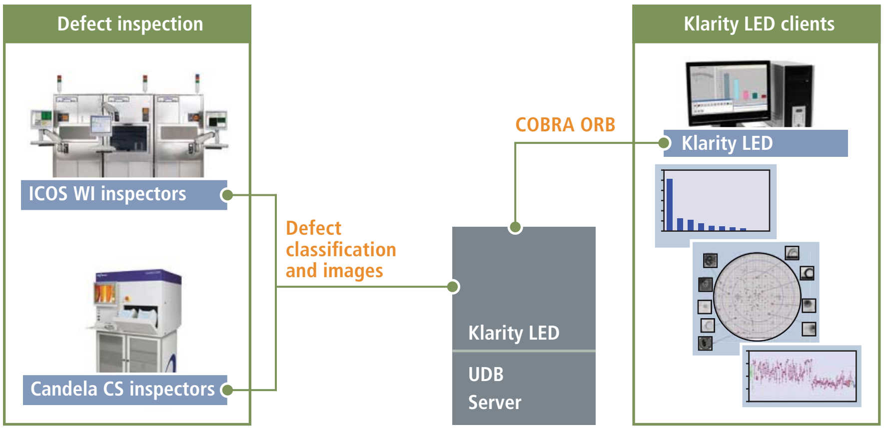

FIG. 1. Typical data flow for Klarity LED.

Automated analysis features within Klarity LED include the following: excursion monitoring and automated report generation; spatial signature analysis (SSA); and defect source analysis (DSA).

Motivation

Defect reduction has always been an on-going effort at Lumileds. The defect group has been successful in driving defect-reduction programs to meet the target yield, but the methods currently employed require a substantial effort from each member of the team.

The current method of defect analysis at Lumileds relies heavily on manually sorting and reviewing defect data from the inspection tools. In the event of an excursion, it usually takes from several hours to a day to review the defect data of the affected lots or wafers.

The data review is performed in the cleanroom via a tool-specific offline image-review station. This can be a tedious and time-consuming task. And once the "problem wafer" is identified, the engineer has to identify which layer caused the problem and which module/process is responsible. Thus, it may require days of analysis and process optimization before the issue can be resolved.

The engineer will typically spend about 2-3 days per week analyzing the defect-inspection data, identifying excursions and generating the weekly yield report. This report is then presented and discussed during the weekly yield meeting. Thus, the

Joe NG and Lixia Huang are with PHILIPS LUMILEDS LIGHTING *in Singapore, while Richard Yeoh and Chee Yong Lim (Singapore), Ichiro Oshima and Katsumi Neishi (Japan) and Christopher Jones and John Robinson (California) are all with* KLA-TENCOR CORPORATION.

majority of the engineer's work week can easily be consumed just to generate this weekly yield report.

Data flow

The data-flow concept for using Klarity LED software within a more comprehensive defect-analysis scenario is depicted in Fig. 1.

Wafer-inspection tools, namely ICOS WI for patterned LED wafers and Candela CS for un-patterned wafers, send defect data in the form of KLARF files to a centralized Klarity Unified Database (UDB). Each KLARF contains defect information, such as defect ID, defect location and defect size. Defect patch images from the inspection tools can be linked to individual defects via embedded pointers and uploaded to the UDB.

Klarity LED clients are installed on PCs (either in the office or clean-room), and are linked to the UDB via the existing network. Clients can perform queries to generate wafer-maps, control charts, defect Pareto charts and defect image galleries, etc.

The desired outcome of this effort at Lumileds was to enable defect-control engineers to use Klarity LED features that would allow them to make more-informed factory-floor decisions. Some of the use cases and test strategies developed during the implementation phase are documented in the following sections.

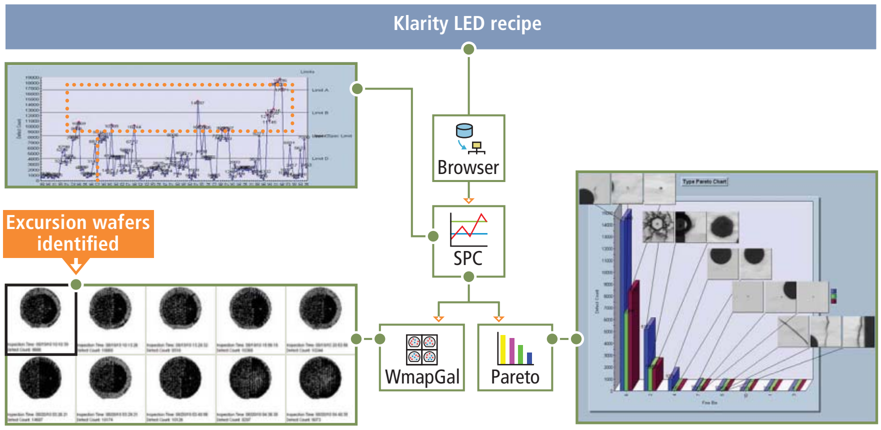

FIG. 2. Excursion detection use case: Klarity LED recipe setup and resulting SPC charts, wafer-map gallery and defect type Pareto.

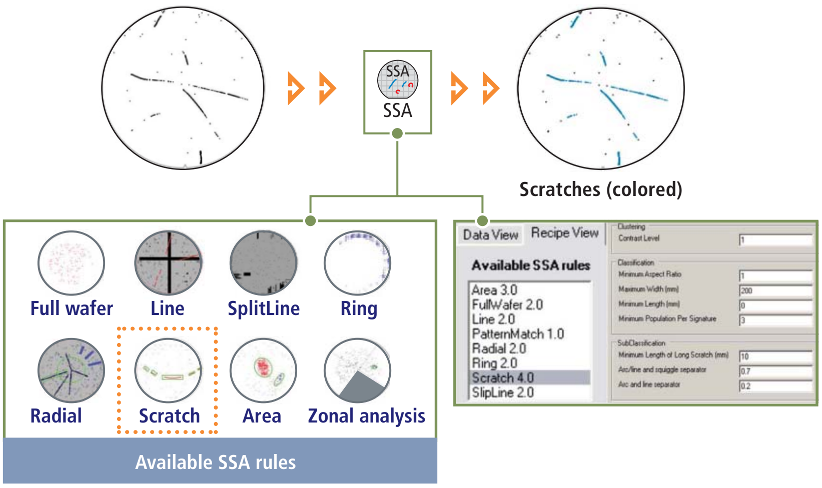

FIG. 3. Spatial signature analysis (SSA) flow.

Use-case 1: Excursion detection using SPC charting

Lumileds monitors and detects line excursions through defect trend charting. Before the introduction of Klarity LED, operators on the production floor would manually input the inspection data and the defect engineers compiled this data on a weekly basis. Manual input of data is both time-consuming and highly prone to human error.

In the event of an excursion, the defect engineer often investigated the issue by going into the clean-room to review the wafer maps one by one on the inspection tool. The engineer often had to spend hours in the clean-room to review the data wafer by wafer or lot by lot, depending on the extent of the issue.

With the introduction of Klarity LED, defect-analysis recipes can be created to automatically generate statistical process control (SPC) charts. These charts can then be used for defect trending and excursion detection. Trend charts can be generated for daily, weekly or monthly tracking of defect levels. The defect engineer can also set SPC limits and have Klarity LED automatically notify them should an excursion occur. These functions can all be done using simple and intuitive graphical recipes as shown in Fig. 2.

Use-case 2: Using SSA to identify signatures on wafers

Along with the ability to perform defect trending and monitoring, the ability to flag and identify wafers that exhibit certain predetermined spatial signatures can be a powerful tool. The defect engineer can use this capability to monitor known, intermittent process issues or to help in identifying the root cause of certain defect excursions.

Klarity LED incorporates spatial signature analysis (SSA) to quickly identify wafers with specific defect signatures. The user "trains" the SSA node by customizing rules via an SSA recipe editor and using sample wafer data having the signature of interest. Once done, the user will save the rule settings as an SSA recipe and incorporate this SSA recipe into the Klarity LED recipe for analysis as shown in Fig. 3.

In one case study, SSA was employed to quickly identify the source layer for a specific nuisance defect (non-yield-limiting defect). This nuisance defect is often referred to as a "fish-scale" defect. Fish-scale defects, if they occur in a massive amount, form either a "donut" or "ring" signature on the wafer, which is very unique. The lot-to-lot variation

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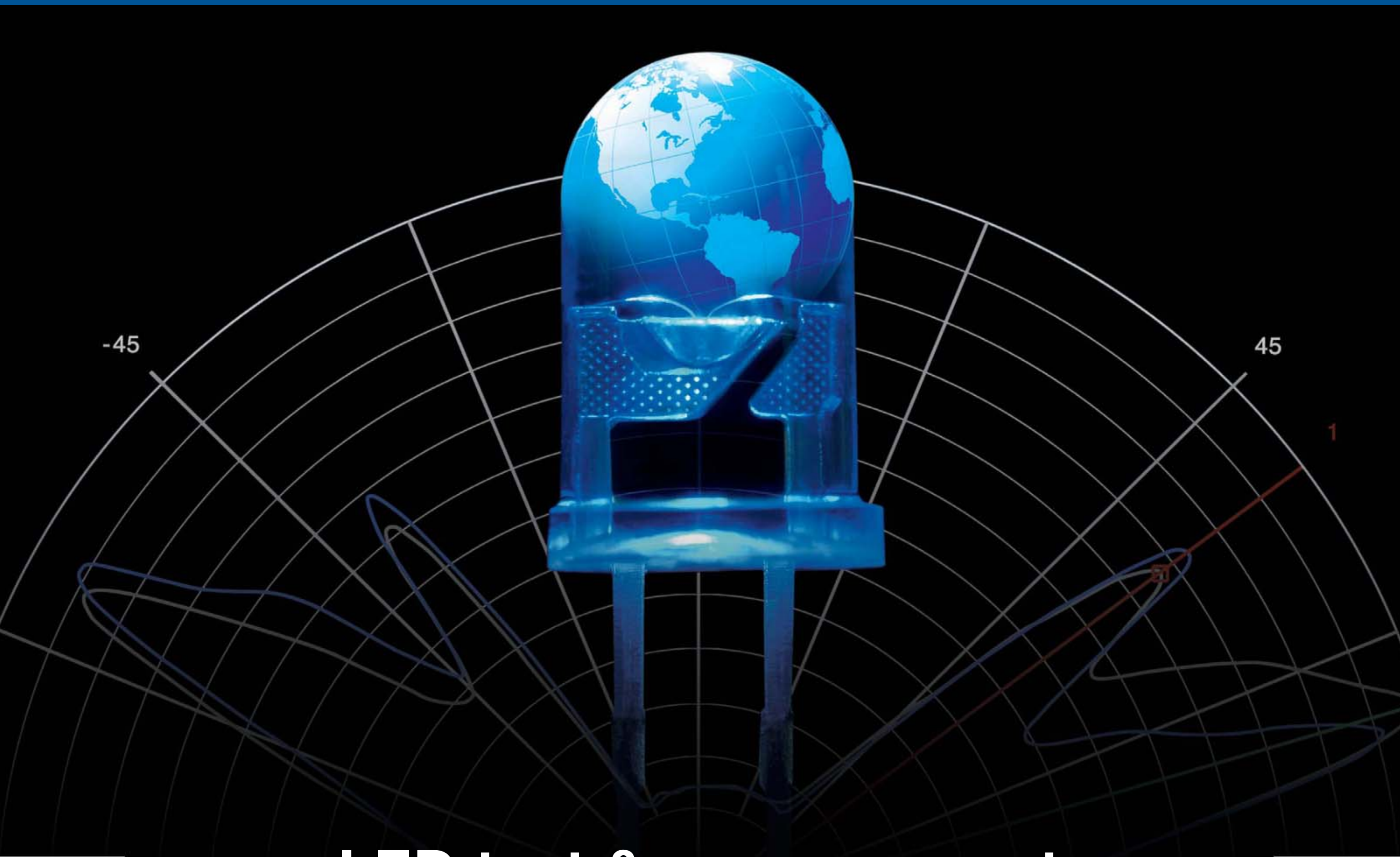

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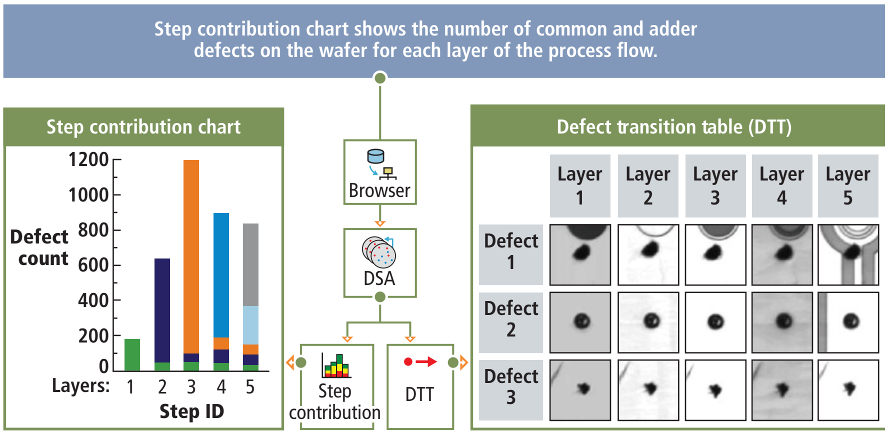


FIG. 4. **Example of a typical recipe with defect source analysis (DSA) and defect transition table (DTT) nodes.**

for this defect type is quite high, leading to false excursion events. After implementation, the true yield-limiting lot-to-lot variation could be identified.

In another case study, it was observed that on some wafers there was high defectivity due to defect clusters at the edge of the wafer. Using the zonal-analysis feature of Klarity LED, Lumileds was able to quickly quantify the location of these specific clusters. Trend charts were set up to monitor occurrence of the edge signatures. Wafers with signatures were singled out using SSA and SPC to determine the locations with a high concentration of edge clusters. With this information the defect engineer could perform additional analysis to further narrow-in on the root cause of the excursion using the DSA capability discussed in the next section.

Use-case 3: Using DSA to determine root cause

One of the key elements of defect reduction is to determine which layer/process step is producing the defects. Knowing this, the engineer can then go on to determine the root cause of the problem and make the right decision to rectify the problem.

Defect source analysis (DSA) is a powerful tool to help the defect engineer narrow the search for the source of problem. It enables the engineer to trace the transition of defects on a wafer as the wafer moves from one layer to the next layer in the process flow, clearly identifying which defects are common to multiple inspections and which are newly added (so-called adders).

The DSA function is further enhanced via a defect transition table (DTT) feature. The DTT allows the user to track how a defect's morphology changes from layer to layer along the process flow, as seen in Fig. 4.

Conclusions and results

Klarity LED has demonstrated the ability to significantly improve the efficiency of systematic defect-analysis capabilities to support a high-volume LED production environment. Incorporating various options to sort, filter, display and analyze defect-inspection data produced many meaningful interpretations for the user.

The bottom line is a significant improvement in both the timeliness of data and the accuracy of analysis to support improved yields at increasingly-higher production volumes.

Based on the results of the above-described use cases, it is anticipated that further deployments and extensions to KLA-Tencor's Klarity LED will play a key role as Philips Lumileds Lighting continues to enhance its LED production capabilities and to introduce new leading-edge LED devices.

LED lighting must work with legacy dimming technologies

To achieve broad market success, LED lighting manufacturers must deliver products that offer dimming capability that is at least equivalent to incandescent lighting, and SSL luminaire design must support legacy dimming controls, explains **DAVID COOPER.**

Many potential applications for LED-based solid-state lighting (SSL) will require dimming capabilities. Dimming not only provides mood lighting, such as in a restaurant or living room, but also increasingly serves to reduce energy consumption by only providing the light level actually needed at any given moment. For example, lights in a parking garage or along a residential street could be dimmed to a low level late at night and only brought up to full brightness if a motion sensor detects activity in the area. Lights over a wide area may be linked using wireless technology to form a local network, with sophisticated sensing, control and monitoring capability through software to optimize the light levels under all conditions. To succeed broadly, SSL luminaire makers must deliver dimmable fixtures that also work with legacy incandescent dimming-control technology.

The fact that LEDs react instantaneously to changes in power input makes SSL especially appropriate for dimming scenarios. Indeed LED lighting offers the potential for dramatic improvements in energy consumption due to the combination of light-source efficiency and compatibility with efficient dimming schemes. In contrast, previous lighting technologies such as metal halide (MH) or high-pressure sodium (HPS) react extremely slowly, and it is not technically feasible to control the brightness of such lights in real time.

Dimming capability can therefore be considered as a key advantage that can be a factor in growing the general acceptance and use of LED lighting. But LED luminaire makers face a challenge in designing products that work with a variety of legacy dimming-control technologies and in some cases that offer the ability to operate in emerging wireless-network-control scenarios.

DAVID COOPER *is the North American Applications Engineering Manager at AEG Power Solutions (www.aegps.com).*

LED dimming technology

Luminaire designers must first understand the related but separate concepts of the mechanism used to feed the dimming information into the luminaire, and the technique used to actually reduce the brightness of the LEDs. First let's discuss the dimming techniques for LEDs. There are two basic alternatives that can be used to reduce the light output of the LEDs – analog dimming and pulse-width-modulation (PWM) dimming.

Analog dimming simply controls the drive current fed to the LEDs. Full brightness uses the full current. The driver electronics linearly reduces the current to dim the LEDs. Analog dimming can be simple to implement but may not deliver the best overall performance. The efficiency of the LEDs tends to drop at reduced currents. Moreover, the LEDs may not produce a consistent color at lower drive currents.

For PWM dimming, the driver electronics supplies pulses of full-amplitude current to the LEDs. The driver varies the duty cycle of the pulses to control the apparent brightness. PWM dimming relies on the capability of the human eye to integrate the average amount of light in the pulses. Provided the pulse rate is high enough (typically about 200 Hz), the eye does not perceive the pulsing but only the overall average.

PWM dimming requires the addition of a PWM controller and a MOSFET switch in the driver electronics at the output of the DC power supply. PWM dimming is generally more complex to implement than analog dimming, but PWM dimming maintains high efficiency and ensures the LED light output does not vary in color.

Now let's discuss how dimming control

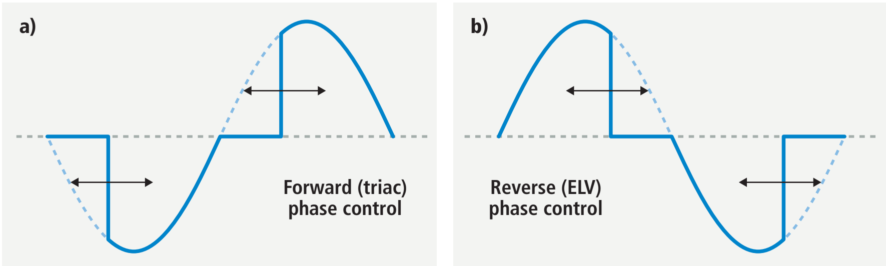


FIG. 1. Phase-control dimmers reduce the lamp brightness by cutting out part of the AC waveform. A forward-phase triac dimmer (a) cuts out a portion of the AC waveform at the leading edge of each half sine wave. In contrast, a reverse-phase dimmer (b) cuts out a portion of the AC waveform at the trailing edge, so that the dimmer turns off part-way through the sine wave.

information is conveyed to the driver electronics in an LED-based luminaire. We're all familiar with the wall dimmers sold for home use, but SSL will be used in a range of scenarios from retrofit luminaires to networked lighting systems with programmatic controls. Luminaire designers must understand the ways in which customers will deploy their products and support the appropriate control schemes.

Dimming information can be carried through the AC wiring, a dedicated analog input, a dedicated digital input, or a wireless interface or network. Each of these options has some advantages and some drawbacks, and different options are appropriate for different applications.

In this article we will focus on dimming signals carried through the AC wiring and how a luminaire can support such dimmers. Table 1 summarizes these scenarios. In a second article planned for a future issue of *LEDs Magazine*, we will cover dimming controls that rely on dedicated analog or digital interfaces, and networks.

Generally speaking, dimming control technologies including signaling schemes and control-information formats are common to any lighting technology – they are not specific to LED lighting. Indeed most of the schemes predate SSL. The majority of LED luminaires will be retrofitted into existing installations and they must be able to interact with the existing lighting controls.

Dimming interface	Advantages	Disadvantages
AC wiring (phase-cut)	No control wiring required Can use existing phase-cut dimmers	Some dimmers require a minimum load May exhibit flickering Difficult to cover wide AC voltage range Cannot dim smoothly to zero
AC wiring (voltage)	No control wiring needed	Only suitable for dedicated applications

TABLE 1. Dimming control options include schemes that rely on existing AC wiring or dedicated interfaces. The former are covered in this article while the remainder will be addressed in part 2 of the article in a future issue of *LEDs Magazine.*

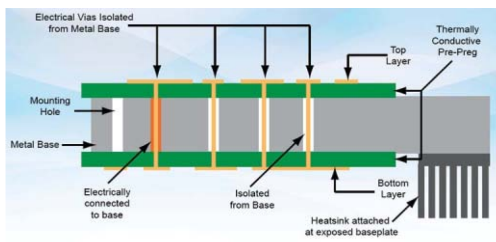
AC phase control

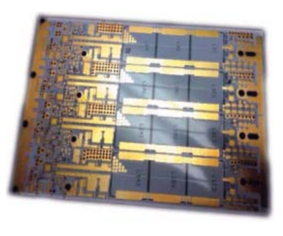
A widely used form of brightness control is the familiar triac-based dimmer that is present in many residential applications. Triac dimmers operate by cutting out a portion of the AC waveform. The most common type cuts out a portion of the leading edge of the AC waveform, as shown in Fig 1a. The dimmer senses each zero-crossing of the AC input, and waits for a variable delay period before turning on the triac switch and delivering the AC to the load. The AC input to the light therefore has a bite out of the leading edge of each half sine wave.

A second similar type of dimmer operates in the reverse manner, by cutting a portion of the trailing edge of each half sine wave, as shown in Fig. 1b. This type of dimming is sometimes called reverse phase control, and is designed for use in electronic low voltage (ELV) applications.

Phase-control dimmers were originally developed for incandescent lighting, where the lamp brightness is directly dependent on the average power in the AC input. By cutting out a portion of the waveform, the power is reduced and the lamp becomes dimmer. However, this is not the case with LED lighting, because LED luminaires contain a power supply and driver whose primary function is to supply constant current to the LEDs regardless of the AC input voltage.

If you connect a constant-current or constant-voltage power supply to the output of a phase-control dimmer, the power supply will attempt to compensate for the missing portions of the AC waveform. As the amount of phase cut increases, the power supply will maintain its output voltage by





drawing higher input current, and the LEDs will remain at normal brightness. Eventually, when the dimmer setting is very low, the power-supply feedback circuits will no longer be able to compensate and the power supply output will collapse.

For an LED luminaire to respond correctly to a phase-control dimmer, it is necessary to add several functional blocks into the driver electronics, shown in orange in Fig. 2. A sensor monitors the AC input waveform before the power-factor-correction (PFC) stage and generates an output signal proportional to the amount of phase cut. The design in Fig. 2 passes the output signal through an isolation circuit for safety to the secondary side of the power supply and serves as an input to the PWM controller. The PWM controller drives the MOSFET switch connected at the output of the DC-DC converter. The MOSFET produces constant-voltage pulses that are converted to constant-current pulses by the LED driver. When no AC phase-cut is detected the output is driven at 100% duty cycle to give full brightness.

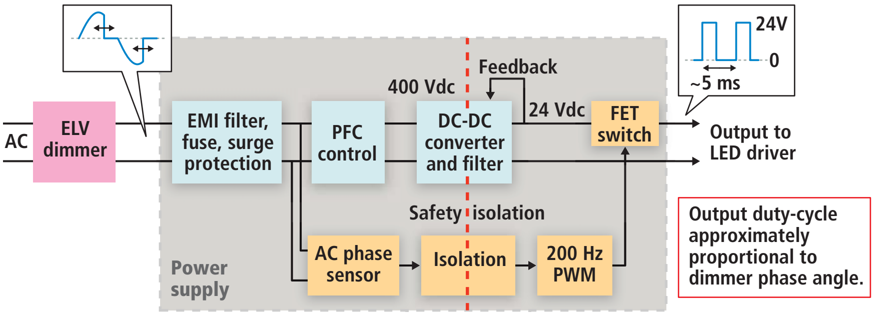


FIG. 2. Power-supply block diagram for phase-control dimming. An LED driver needs additional components, including an AC phase sensor, a PWM controller and a MOSFET switch, to support phase-cut dimming.

AC input voltage control

Another approach that can be used for dimming most lighting technologies including incandescent, MH, and HPS lamps is to simply reduce the AC input voltage. This is particularly suitable for street lighting, to reduce energy consumption during off-peak hours. For example, the AC voltage can be reduced by 10% in late evening, by 20% after midnight, and then brought back to normal in the early morning. The technique is most effective when a single voltage controller can be used at a central point with the output distributed to multiple lights in the area.

But voltage control is yet another technique that isn't inherently compatible with standard LED lighting. As with phase control, the LED power supply will compensate for the reduction in voltage and will maintain a constant-current output to the LEDs. SSL luminaire designers can accommodate voltage control by adding an AC voltage sensor to control the output duty-cycle.

The design for such a system is almost identical to the phase-control example in Fig. 2, except the phase-sensor block is replaced by a voltage-sensor block. Because an incandescent filament behaves approximately as a pure resistive load, a drop in input voltage of 10% results in a drop in power (brightness) of approximately 20%. The AC voltage sensor in an LED power supply would be designed to simulate this behavior rather than providing a linear control, so that the variation of LED brightness more closely matches that of an incandescent lamp.

In this first article of a two-part series, we have discussed dimming control through the AC wiring. In the next issue, we will look at dimming using a separate analog, digital or wireless input. Whichever technique is used, the virtually instantaneous response of LEDs to changes in drive current allows great flexibility and will support ongoing and future initiatives to reduce energy use.

Active cooling can boost lumen output in LED lighting

Active cooling technology can offer thermal capabilities that are superior to passive heat sinks and can raise lumen output and extend LED life in solid-state lighting, says **RYAN AHEARN**.

This will be a big year for LEDs in general lighting applications, with expectations of 59% growth compared with 2010. Retrofitting fixtures or replacing existing incandescent and fluorescent lighting solutions with solid-state lighting (SSL) is gaining steam – and quickly. Users value LED lights for their energy efficiency, long life and low maintenance. LEDs are saving businesses and cities millions of dollars a year in energy and maintenance costs and providing consumers with a more-energy-efficient, high-quality light for their homes.

However, further advancements are still required to make LEDs the lighting technology of choice for retail, residential and outdoor lighting applications. Cost and lumen output are currently the main limitations to the widespread adoption of LED lighting.

The cost of manufacturing LEDs is expected to decrease substantially by 2015. The US Department of Energy forecasts that the manufacturing cost of an LED luminaire or fixture will fall by about 40 to 45 percent over the next five years. These cost savings will be further enhanced by government subsidies and rebates.

Lumen output is another key factor in the adoption of LED lighting. Although LED technology continues to advance, high-lumen-output LED applications cannot be achieved with passive cooling alone. LED lights cooled by a passive heat sink, rather than with an active cooling solution like a synthetic jet, are inherently larger, which makes retrofitting difficult. A smaller heat sink may result in a lamp or luminaire that is less reliable due to heat damage to the LEDs, or a source that produces insufficient light for market success.

RYAN AHEARN *is a Product Manager at Nuventix (www.nuventix.com).*

Thermal issues in LED lighting

Thermal dissipation is a key factor that limits the lumen output of an LED light. LED bulbs are available that are as much as 80 percent more energy efficient than traditional incandescent lighting, but the LED components and the driver electronics still create a considerable amount of heat. If this heat is not dissipated properly, the LED's quality of light and life expectancy decrease dramatically.

Heat sinks solve thermal management problems for low-lumen LED lamps. Lighting manufacturers have had little difficulty developing viable 40W-equivalent LED retrofits for A-lamps, and many also have solutions in place for 60W-equivalent lamps. It is when you get into the high lumen counts that thermal management becomes a challenge. A heat sink alone will not cool a 75W- or 100W-equivalent lamp.

The demand for these high brightness bulbs is evident – 75W and 100W lamps make up a significant piece of the lighting market. Businesses are eager to take advantage of the energy and maintenance savings inherent with LED lighting. The Energy Independence Security Act of 2007 will be requiring higher efficiency bulbs starting in 2012. These new requirements have consumers looking for an incandescent replacement that has a good quality of light and a long life in addition to a high lumen output.

In order to reach the desired lumen values in a fixed form factor, active cooling may be required to dissipate the heat produced by the LED components. Some active cooling solutions, such as fans, don't have the same life expectancy as the LED itself. In order to create a viable active cooling solution for high-brightness LEDs, the method of thermal management must be inherently low in energy consumption, flexible enough to fit into a small form factor and have an expected life equal to or greater than that of the light sources.

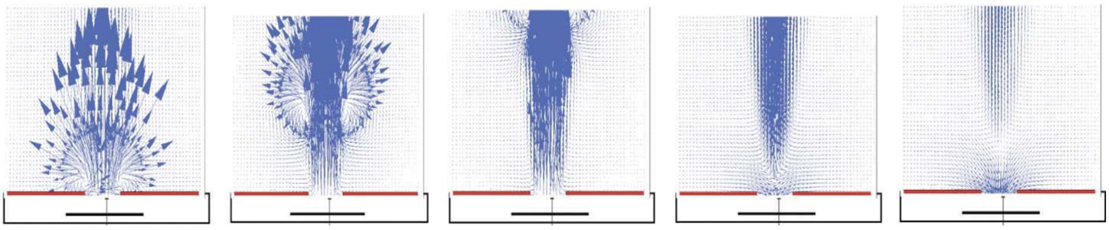


FIG. 1. Velocity vectors of the synthetic jet flow as air is expelled.

Synthetic jet cooling

Synthetic-jet technology provides an active cooling solution for LED lighting, and has been adopted by many major global lighting companies. The compact cooling modules address all of the constraints currently hindering the development of LED lighting: effective heat dissipation, small form factor and reliability.

Synthetic jets are an alternative to the traditional fan and are much better suited to the increasingly challenging demands of LED thermal management. The jets are formed by periodic suction and ejection of air out of an opening that is caused by the motion of a diaphragm, as displayed in Fig. 1. The first three panels in Fig. 1 show the ejection phase, during which a vortex accompanied by a jet is created and convected downstream from the jet exit. Once the vortex flow has traveled well downstream, ambient air from the vicinity of the opening is entrained, as displayed in the last two panels of Fig. 1.

The rapid-fire pulses of turbulent air, typically 30 to 200 pulses per second, break up the thermal boundary layer and increase the amount of heat transferred away from the heat source (most often the LED heat sink), allowing more heat to be removed with less air. These rapid-fire pulses of air can be directed precisely where cooling is needed, such as the fins of a heat sink, further lending to the synthetic jet's thermal efficiency.

Synthetic-jet technology offers several benefits. First, the technology makes it possible to remove more heat with less air and does not require additional air to be drawn in as with conventional jets. Heat sinks can be up to two-thirds smaller and lighter, therefore reducing the size of the light engine and making retrofitting more viable, while still maintaining the lumen output necessary for the light to be effective. Synthetic jets are 50% more thermally efficient in removing heat from the source compared to laminar flow normally associated with active cooling.

The synthetic jet form factor lends itself to the design of any LED lighting fixture: retrofit, outdoor lighting, retail, industrial lighting, etc. Synthetic jets have the unique ability to bend airflow in ways that are nearly impossible with traditional air movers, allowing unique designs.

Finally, the form factor of the synthetic jet also lends itself to durability, which is essential in ensuring the long life of the LED light. The modules contain frictionless moving parts which make them reliable, long lasting, resistant to dust and particle contamination and virtually silent.

Making retrofit lamps brighter

Let's consider an example of an LED retrofit lamp that utilizes synthetic-jet technology. Ledon Lamp GmbH, based in Austria, focuses on making high-efficiency LED lamps. Ledon created prototypes of 75W- and 100W-equivalent, incandescent-replacement LED lamps in a near-A-lamp form factor. Although not a true A-lamp envelope, the company does expect the bulb to fit into the majority of applications. With the help of synthetic-jet thermal management, Ledon was able to demonstrate the appropriate values of lumen output, which have never been achieved before, with the help of synthetic jet thermal management.

To achieve the 75W and 100W equivalency, Ledon included the synthetic jet in the top side of the bulb. Located above the synthetic jet is a heat spreader that conducts heat from the LEDs to the heat sink. The heat sink forms nozzles for the synthetic jet to push air through and distribute the airflow to the heat sink fins. The nozzles above the synthetic jet are radially distributed at the edge of the heat sink, between the fins, to allow the synthetic jets to achieve good heat exchange with ambient air.

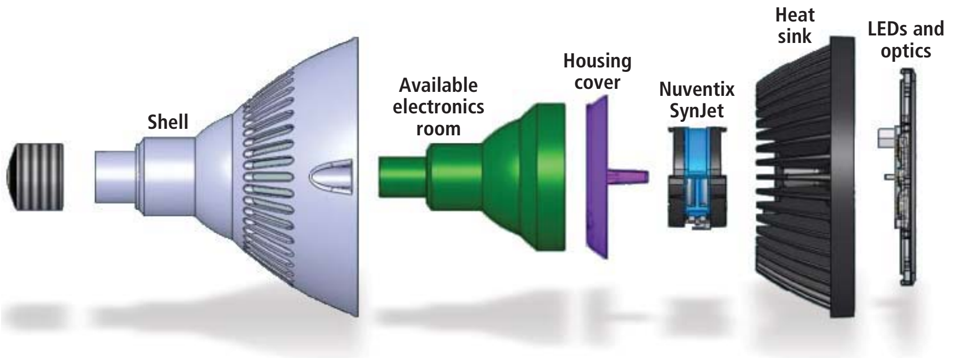


FIG. 2. PAR38 reference-design model with Nuventix SynJet engine.

FIG. 3. Synthetic jet engine with oscillating diaphragm.

In order to cool the driver electronics, one chamber of the synthetic jet is connected to the housing of the driver. Vents on the bottom of this housing are opened to allow the exchange of air, thereby effectively cooling the driver electronics and enabling 75W and 100W LED incandescent replacements. All of this flexibility in design would not have been possible without the synthetic jet's flexibility to direct air in multiple directions for cooling the drive electronics and LEDs.

PAR38 reference design

Nuventix has also created a thermal-management reference design for a PAR38 retrofit lamp (Fig. 2). The reference design, when used in conjunction with the Nuventix SynJet (Fig. 3), provides lighting designers with a system for building an LED array with an output of more than 2500 lm that fits into the PAR38 form factor. In contrast, today's typical LED-based PAR38 replacements deliver about 1500 lm.

The design features a Texas Instruments (TI) custom electronic driver control device, which enables a smaller form factor by integrating discrete components into a single IC.

The SynJet enables up to 40W of cooling in the PAR38 reference design while consuming less than 500 mW of power. Additionally, the SynJet and TI's IC provide lamp designers more design-option flexibility, enabling more lumens in a smaller form factor and thereby using fewer LEDs.

Raleigh LED lighting projects demonstrate durability and savings

Beginning in 2007, Raleigh, North Carolina, was among the first cities to install LED-based lighting, and has demonstrated energy and maintenance savings over a long term with bette lumen maintenance, says **MAURY WRIGHT**.

In *LEDs Magazine*, we write about LED-based lighting installations, and projected energy and maintenance savings, every week, but it's unusual to have a case study in which solid-state lighting (SSL) has been installed for years. Raleigh, North Carolina completed its first outdoor SSL project in 2007, and positive results, including excellent lumen-maintenance performance, continue to accumulate. Moreover, Raleigh's lengthy experience also illustrates the pace of progress in LED technology. The city's earliest projects delivered good results while the latest projects show even better results in terms of light quality, energy savings, and payback.

Raleigh began talking with Cree about LED projects back in 2006, according to Assistant City Manager Daniel Howe. The discussion began with Cree's VP of corporate marketing Greg Merritt about Cree participating in a civic artwork project that had an LED-lighting element. Those discussions led to a plan to jointly install and test LED lighting on a much broader scale, and ultimately resulted in the launch of the Cree LED City program in early 2007 (www.ledsmagazine.com/news/4/2/2). Subsequently the DOE assumed guidance of the LED City program (www.ledsmagazine.com/news/7/9/30) but Raleigh remains the standard bearer for LED lighting.

The LED city

According to Howe, Raleigh has undertaken 30-35 individual SSL projects. In aggregate, Howe says the city is saving $225,000 per year on its LED projects, $175,000 of which is in energy savings. Mayor Charles Meeker has been a major LED proponent. In a recent state-of-the-city address, he said, "Our real challenge now is to take some of these pilot projects such as LED street lights and make them everyday applications."

MAURY WRIGHT *is the Senior Technical Editor of LEDs Magazine.*

LED lights in the Carolina Pines park in Raleigh, NC, survived a recent tornado.

The city has undertaken both indoor and outdoor LED projects. Indoor examples include general and accent lighting in the city's performing arts center, and lighting in the mayor's office. However, there are far more examples of outdoor lighting. The city has used SSL in parking garages, to illuminate streets, parks and freeway underpasses, and as lighting for pedestrian bridges. LED up-lights and bollards have been used as landscape lighting. And the city used LEDs in an architectural application to light its convention center façade (www.ledsmagazine.com/news/5/8/27).

Raleigh's first major LED project was in a municipal parking deck and was completed just prior to the launch of the LED City program. The city used luminaires developed by Lighting Science Group. A total of 144 70-watt LED fixtures replaced existing 188W high-pressure-sodium (HPS) fixtures.

Results from the first project

The energy and maintenance savings of the first project have been well documented over four years at this point. The city installed the LED lights on a dedicated circuit so that it could precisely measure power usage. In energy and maintenance, the LEDs have saved the city more than $13,000 per year.

After the initial installation, Raleigh also commissioned an independent public safety and security consultant to evaluate the lighting performance, and a market-research firm to study public perception of the lights. The city published positive results from both in a report that is still available on its website (http://1.usa.gov/jkS3R5). Howe remembers being surprised when the public study revealed that "the people said it was brighter and safer even though the lights cast 11% fewer lumens."

The real benefit now, however, of a project that has been lit for four years is the opportunity to evaluate lumen-maintenance performance. All light sources degrade over time. But some naysayers have been especially critical of LED lumen maintenance and how fast SSL products would degrade to L70 (70% of initial light output) – essentially the equivalent of a failed lamp. LED proponents often champion an expected lifetime in the 15-year range but realizing such expectancy requires LED technology with a slow rate of decrease in light output.

LED life projections

As with most LED projects, Raleigh projected the parking-garage light installation energy savings and payback period based on luminaire specifications – including lumen maintenance – and typical operating scenarios. The city expected the lights to exceed L70 for 50,000 hours of service, equivalent to 5.7 years if operated 24 hours a day. But because the garage level with the SSL retrofit was exposed to some ambient daylight, the city used a photocell to power-down some of the lights for 12 hours each day, extending the expected life to 11.4 years for those luminaires. Obviously the use of photocell control adds to the energy savings as well.

During 2010, Raleigh city workers returned and measured the light output of the LED luminaires. Howe said, "The degradation was half of what we expected." The city's projections relied on a linear depreciation of light output over time. There is no guarantee of the linear response. Still Howe is optimistic that the lights will last longer than expected. He said, "They may last 2 or 3 or even 5 years longer than we projected."

Raleigh's four years of experience and lengthy list of projects also offer insight into how quickly LED lighting is maturing. Indeed the report on the municipal garage (see URL above) noted that LED lights with 75% better efficiency had come to market during the planning and installation of that first SSL project.

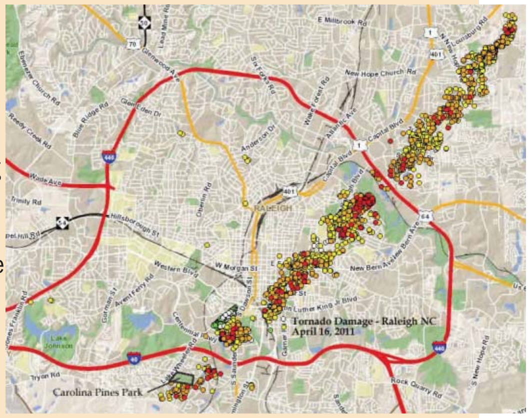
Following its success with LEDs in the municipal parking garage, Raleigh made the decision to deploy LED lighting in an underground parking garage at its new convention center. Construction was underway on the deck when the city made the decision to utilize LED lighting. Plans had been drawn for 544 220-watt metal halide (MH) fixtures in phase one of the garage project.

To simplify the specification and implementation process, the city chose a BetaLED luminaire that was a one-for-one match for the MH luminaires in terms of light output. Ultimately the city installed 118W LED fixtures in March of 2008. There is a detailed report on the project on the LED City web site (http://bit.ly/jWPGh0). The report projected a three-year payback for the LED lights.

LED lighting survives tornado

Long life and reliability remain a hallmark of LED lighting, but an outdoor installation in Raleigh recently exhibited more durability than anyone could reasonably expect. A number of US cities, especially in the southeastern portion of the country, have suffered devastating tornadoes this year. On 16 April, 62 tornadoes touched down in North Carolina destroying 450 homes, and Raleigh suffered significant damage. But exterior LED lighting in a city park near the tornado path suffered no damage.

The city installed LED lighting in the Carolina Pines park in late 2007 and early 2008. The project included 35 fixtures where 289W metal halide (MH) lights were replaced with 128W LED fixtures. Over the past few years, the city has documented just over $2000 in annual energy savings for the project, according to Assistant City Manager Daniel Howe.



LED lights survived a recent tornado in Carolina Pines park that lies at the southwest edge of the tornado's path.

Howe seems more impressed with the maintenance record of the LEDs. He said that prior to the retrofit, "Carolina Pines often required two visits a week to maintain the exterior lighting system." Howe said that each visit cost the city a minimum of $75 to $100. But Howe said the city has not experienced even one maintenance call on a single light since the LED installation. The city has documented maintenance savings of over $1400 per year.

Still, Howe expected damage to the lights from the tornado. Despite substantial numbers of downed trees and other damage in the park, which was in the path of the storm that took three lives and caused millions of dollars of damage in Raleigh, the LED lights survived intact and operational. Howe said it is likely that with MH or HPS lights, at a minimum, a number of lamps would have been destroyed by flying debris and ballasts would have been blown by the power surge. ◂

The middle deck in a Raleigh municipal parking garage was the city's first LED project.

LED lighting in the Raleigh convention-center parking structure.

Maturing LED technology

Looking back, the more significant part of the story came with the second phase of the project when the city lit a second level of the garage with LEDs in August 2009. The second time around, 51W LED fixtures supplied the equivalent light of 220W MH fixtures. LEDs had advanced significantly in efficacy in 17 months.

Moreover, the fixtures use BetaLED's modular light-bar design that hosts the individual LEDs along with the company's NanoOptic total internal reflection (TIR) lenses to form a beam pattern (for more information on beam patterns and TIR, see www.ledsmagazine.com/features/7/9/8). According to Howe, the luminaires used in the first phase relied on five light bars to generate the required light. The luminaires in the second phase needed only two light bars – 60 fewer LEDs per fixture.

The reduction in the required number of light bars clearly illustrates the ramp in LED brightness. And the luminaires with fewer light bars will likely offer additional cost savings over the life cycle of the project.

Raleigh modeled the projects on a 15-year life cycle that will require the city to replace the LED sources at least once and probably twice over that period. The city may be able to simply replace the light bars rather than the entire fixtures. The fewer the light bars involved, the greater the savings.

LED lessons learned

Raleigh can serve as a broad example for other municipalities considering LED projects based both on the breadth of the experience gained and also on unexpected lessons learned (see Sidebar "LED lighting survives


Raleigh combined solar cells and LED lighting at a remote operations center.

tornado"). Indeed, LEDs shine in some applications for reasons other than low power, and the maintenance savings can come from unusual circumstances. Howe said LED lights deployed in a greenway underpass have proven durable to mischievous acts by youths that had led to burst bulbs in legacy lights.

Also, Howe was willing to break down some of the different ways that Raleigh has deployed SSL, and to offer an opinion as to how mature SSL is relative to the specific applications. Considering parking garages, Howe said, "The cost effectiveness of LEDs in low-bay lighting is way over the tipping point. Everybody should be installing LEDs in such applications."

The case for street lights is almost as strong. Howe suggested the viability for LED street lights still depends to some extent on the utility involved and the rate structure. Utilities that offer a lower rate for LED installations make the application more viable. He said that investor-owned utilities such as Progress Energy, which serves Raleigh, are being the most proactive with such rates.

Howe also stressed that Raleigh's experience with LEDs has been very positive for the city and its citizens. He said, "We haven't done an LED project yet that hasn't penciled out financially." He said every project has brought positive cash flow to the city. He also dispelled the notion that LEDs only make financial sense when grants or rebates are involved. Howe said, "We are now doing projects that are market based."

The viability of LED lighting will only grow stronger going forward, particularly as prices of LED luminaires continue to fall. Howe offered another thought on the future. He said that energy prices will continue to rise, so energy savings attributable to LED lighting might be greater than people project when they compare light sources.

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Is the lighting industry now in the mood for OLEDs?

OLEDs are evolving as complementary sources for indoor lighting, says Verbatim's **JEANINE CHROBAK-KANDO**, who provides an overview of technology, desirable characteristics and the current status of today's OLED lighting products.

Organic light-emitting diodes (OLEDs) now appear in a host of commercial electronics applications, most commonly in mobile phones, MP3 players, radio display panels in high-end cars, tablet PCs, and other consumer gadgets. An understanding of OLED technology has been with us for over half a century since researchers at Nancy-Université, France, first observed electroluminescence in organic materials in the 1950s. The affect was only apparent when relatively high voltages were applied to the materials.

The technology currently employed is attributed to W. Tan and A. VanSlyke, and was invented while these researchers were working at Kodak. The breakthrough was to produce a technology that operated at a low voltage and was relatively economical to manufacture. Today's OLED construction is based upon a Kodak patent, and in November of 1997 Touhoku-Pioneer started the first mass-production of OLEDs, initially for car dashboard displays.

The first OLED screens in personal digital assistants (PDAs) appeared in 2004. By 2008 consumer electronics companies were demonstrating large-screen televisions with high resolution, high contrast ratio and peak luminance of 600 cd/m^2.

The drivers of OLED development in these display applications have been the need to reduce cost, weight and power consumption and to provide a better user experience through improved contrast and viewing angle. But what about OLEDs as general light sources? To understand the potential for OLEDs in lighting, let's start with a little technical background.

JEANINE CHROBAK-KANDO *is the Business Development Manager for LED lighting at Verbatim GmbH (www.verbatim-europe.com).*

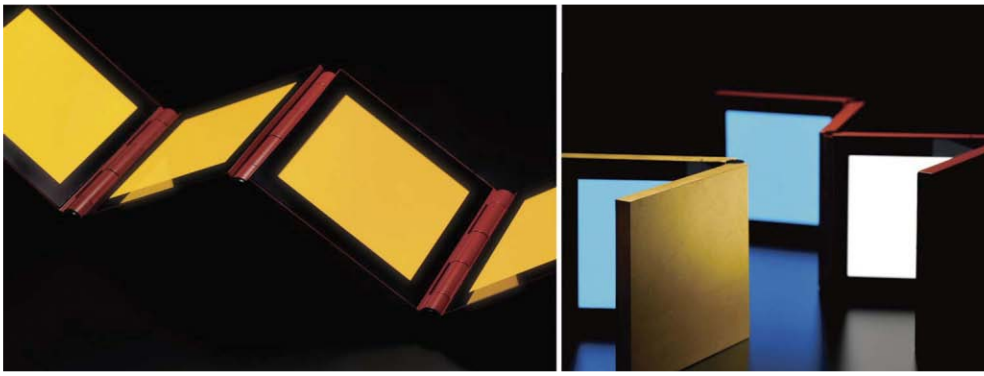

FIG. 1. OLED panels can be dimmable, color tunable and white-tone tunable.

How OLEDs work

OLEDs work by sandwiching a layer of organic material between two electrodes, an anode and a cathode, and depositing the whole thing onto a substrate, typically glass or plastic. When a low DC voltage is applied to the electrodes (positive to the anode, negative to the cathode), light is emitted when electrically-charged particles (holes and electrons) combine within the organic film. The characteristics and intensity of light emitted, and how it is extracted from the OLED assembly, determine its suitability for lighting applications.

One challenge for OLED development engineers has been how to create large panels. In general, the larger the panel that can be printed in one process, the lower the cost of the OLED light – there's no need to fix a lot of individual panels together to achieve sufficient luminous intensity. Limitations in processes and materials determine how large a panel can be made. Another important consideration is the operating life of OLEDs. The higher the light output, the more limited the life of the device, so the most appropriate trade-off for each application has to be made.

OLEDs can be made in one of 3 ways, as shown in Fig. 2. Some leading manufacturers favor the multi-layer type on the left, and this is the simplest process. The tandem construction (right) is a little more complex but delivers more intense light output. It also allows larger formats to be created. Tandem construction is sometimes combined with the multi-layer structure.

The approach taken by Mitsubishi Chemical, which markets OLEDs under the Verbatim brand, is shown in the center of Fig. 1. Narrow stripes of adjacent red, green and blue OLEDs are deposited. This method of production is more complicated but yields two advantages. The first relates to light extraction. Each layer within an OLED has a different refractive index. This causes internal reflections within the device that limit out-coupling – the proportion of light generated that reaches the outside environment. The RGB stripe construction is the most effective in maximizing the light output for a given energy consumption. The second advantage is that the OLED is not only dimmable, as with other types of construction, but also color tunable and white-tone tunable. Dimming does not affect color.

Manufacturing processes for OLEDs seek to maximize light output and minimize pixel defects. To achieve these aims, in place of the dry process of vapor deposition of the layers that make up the OLED, Mitsubishi Chemical uses a wet process. This avoids defects in the OLED structure when microscopic particles of foreign material are encountered.

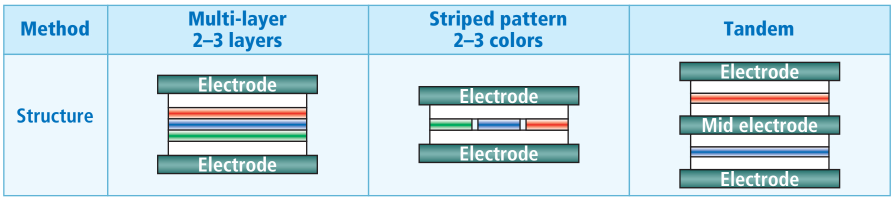

FIG. 2. The striped-pattern approach maximizes light output and enables color tuning.

Desirable characteristics of OLEDs

As mentioned earlier, OLEDs need a large emission surface to be suitable for lighting applications so that they emit sufficient light to be useful. The quality of light, usually expressed as its color rendering index (CRI), is important in rendering colors accurately. Low-power operation, meaning high efficiency in converting electricity to light, is vital in a world focused on reducing energy consumption and CO_2 emissions. Also, in common with the requirements of OLED displays, OLED lights should not contain hazardous substances, need to be simple to operate, and must exhibit fast on/off response.

The CRI of a light source is determined by shining the light onto eight different-colored tiles, numbered R1 to R8, and analyzing the spectrum of the light reflected from the tiles. In general, CRI is quoted as the Ra value, which is the average figure across all of the test colors (R1-R8). R9, the color red, is not used in the calculation of Ra, but is important within the spectrum of human vision, so a high R9 figure is also desirable in OLED lighting. The wavelength of light above R9 (approximately 650nm) contributes little to human vision. Today's OLED panels exhibit an R9 value of 84 and an Ra of greater than 80.

What's available today?

The latest dimmable, color-tunable and white-tone-tunable OLED panels are available in sizes up to about 140 x 140 mm, as shown in Fig. 1. They offer luminance of approximately 1000 cd/m^2 at a color temperature of 3000K, enhanced by a light-extraction film on the luminous surface. Power consumption is about 2W. Panels are typically between 3.6 mm and 8.65 mm thick and have an operating life of over 8000 hours before the output falls to 70% of its initial value.

The white tone is tunable from 2700K – a typical warm-white figure – to about 6500K, equivalent to bright sunlight. Using a simple 3-channel electronic controller located on the back of each panel, the color can be tuned virtually instantaneously. Using this feature, together with dimming, the emotional impact of a lighting scheme based on OLED panels can be changed to reflect the mood required for the environment. For example, bright, white light may be desirable in the morning but more subdued, relaxing lighting with muted colors may be preferable towards the end of the day.

Photography by Toshio Kaneko.

FIG. 3. A Verbatim display designed in collaboration with Uchihara Creative Lighting Design Inc.

The technical protocols for RGB color tuning (DMX) and dimming (DALI) are well established, and low-cost controllers are widely available. Panels are easily calibrated and matched using the controllers to compensate for differences between panels cased by manufacturing process variations. In the near future, there is an expectation that the DALI protocol will be extended to include all aspects of color control, as well as dimming functions.

OLEDs are not yet ready to replace general indoor lighting, as has been suggested by some enthusiasts. However, they are now at the stage where they complement ambient lighting and task lighting to produce beautifully-balanced lighting schemes both in places of work and in the home. Their potential in retail environments and other public spaces is unlimited, and their low power requirements meet the demands of the most ardent environmentalists.

LED DESIGN FORUM

Coordinated circuit protection enhances AC-LED luminaires and lamps

Properly-deployed components can protect AC-LED-based lighting-system designs from over-voltage, over-current, and over-temperature conditions while meeting safety and performance standards, say **BARRY BRENTS** and **DAVID NEAL**.

In recent years, LED technology has made impressive gains in price, performance and manufacturability, and further improvements that optimize LED operation are expected to drive exponential growth in the LED lighting market. Among the most recent commercial developments are AC-LEDs, which can operate directly on line voltage, without the need for an AC to DC converter. But even AC-LEDs are susceptible to line transients that can overheat the components, either causing immediate failure or greatly shortening the useful life of the LEDs. This article will describe a circuit-protection strategy that can help prevent overheating and deliver a reliable solid-state lighting (SSL) product.

When proper thermal management and circuit-protection design strategies are employed, AC-LED technology offers several advantages over conventional lighting, including compact size, component count reduction, energy efficiency, and reduced system cost. But lamp and luminaire designers must design to protect against over-voltage, over-current, and over-temperature conditions.

As with any electronic system operating on line voltage, unprotected AC-LED lighting systems can be damaged by lightning surges that create voltage spikes or ring waves (oscillating waves generated by lighting or other switching elements in the AC power system). A metal oxide varistor (MOV) is often used to help protect lighting systems from lightning surges and ring-wave effects, and helps manufacturers meet safety and performance standards. The MOV clamps short-duration voltage impulses. Lightning tests according to IEC 61000-4-5 and ring-wave tests according to IEEE C.62.41 can be used to simulate these real-life threats in the lab.

SSL designs may need a second protection device for over-current and over-temperature conditions. In both AC-LEDs and DC-LEDs alike, excessive heat at the LED junction can dramatically reduce both the light output and lifespan of the LED.

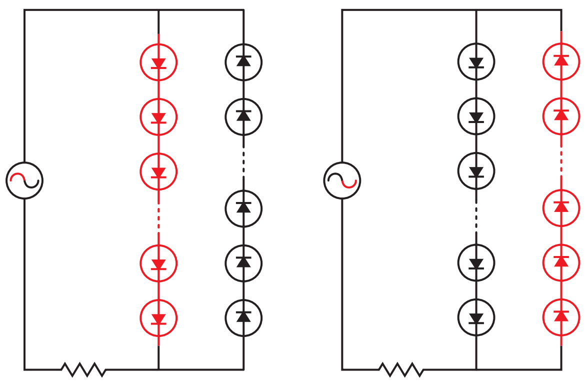

FIG. 1. Typical AC-LED schematic.

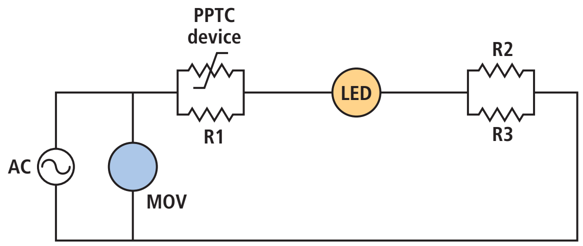

FIG. 2. AC-LED circuit with MOV and PPTC protection.

TE Circuit Protection's PolySwitch polymeric positive temperature coefficient (PPTC) devices help provide over-current and over-temperature protection and can be easily integrated onto a circuit board with the AC-LED. The PPTC acts like a fuse to limit current in a series circuit that drives the LED, yet can automatically reset itself when the fault clears.

Thermal runaway design considerations

To understand the circuit-protection needs, let's consider the potential problem with LEDs due to the fact that they exhibit a negative thermal coefficient. The LED forward voltage (Vf) decreases with increasing temperature. With a constant-voltage power supply, increasing the temperature slightly decreases Vf and increases the current by a relatively large amount. This causes a net increase in power and an increase in temperature. For a given thermal path, the heat transfer may no longer be able to accommodate the increasing power.

In extreme cases, the result is thermal runaway, which may damage the AC-LED if the

BARRY BRENTS *is a Field Application Engineer with TE Circuit Protection.* DAVID NEAL *is an Applications Manager with Seoul Semiconductor.*

Input voltage (V)	70	80	90	100	110	120	130	140	150
Current (mA)	11	13	22	33	44	52	68	86	103 dropped to 13
Temperature (°C)	26	29	36	49	64	79	102	128	142
Light output (lux)	110	430	1010	1710	2320	2950	3550	3800	4000 dropped to 420

1. Light output is measured at 5-inch distance.
2. Temperature is junction temperature
3. Test results will differ with different resistors, thermal design and ambient temperature.

TABLE 1. Test results from a Seoul Semiconductor AN3211 LED with PolySwitch miniSMDC014F protection, using the test setup shown in Fig. 2.

current or power is not limited to prescribed levels. The LED light output varies roughly linearly with the current passing through the LED, within a specified current range. If the current exceeds the manufacturer's recommendations, the LEDs can become brighter but the light output can degrade at a faster rate due to lumen depreciation, shortening the useful life of the component.

Every effort should be made to keep the LED cool for maximum efficiency. LEDs are typically coupled to a heat sink to minimize the junction temperature. Limiting the current or power through an AC-LED helps prevent thermal runaway and has the added benefit of providing better brightness regulation over a wide temperature range, as well as a longer lifetime.

Let's examine an SSL design based on the AN3211 AC-LED from Seoul Semiconductor (Fig. 5). Externally, the LED is treated as an AC-driven component that requires a combination of external resistors to set the operating current based on its forward voltage. The LED's internal construction consists of two sets of diodes in parallel that are of opposite polarity. As shown in Fig. 1, as the line voltage increases on the positive half-cycle, one of the internal strings conducts and generates light; during the negative half-cycle, the other string conducts and generates light.

Fig. 2 shows the Seoul Semiconductor AC-LED AN3211 test setup, where an MOV and a PolySwitch miniSMDC014F PPTC device were integrated on the AC-LED lighting-system board. The MOV serves to limit damage from voltage spikes while the PPTC protects the LED from current and temperature faults.

Table 1 shows the test parameters and results from a series of tests run on the sample circuit, during which the increase in voltage ultimately caused an over-current condition. The tests exhibited normal operation through an increase from 70V to 140V on the input. When the input voltage was raised to 150V the PPTC opened, making the bypass resistor the only path for current flow, and thereby reducing the current draw from 103 mA to 12 mA. The light output also dropped in a corresponding fashion, but the LED was protected. Designers can achieve different results by varying the resistors used in the circuit in Fig. 2.

Over-voltage protection design considerations

Together the MOV and PPTC protect against both voltage transients and over-current faults – whether the over-current is caused by a spike from lightning or another source. Indeed even impulse changes in voltage can produce

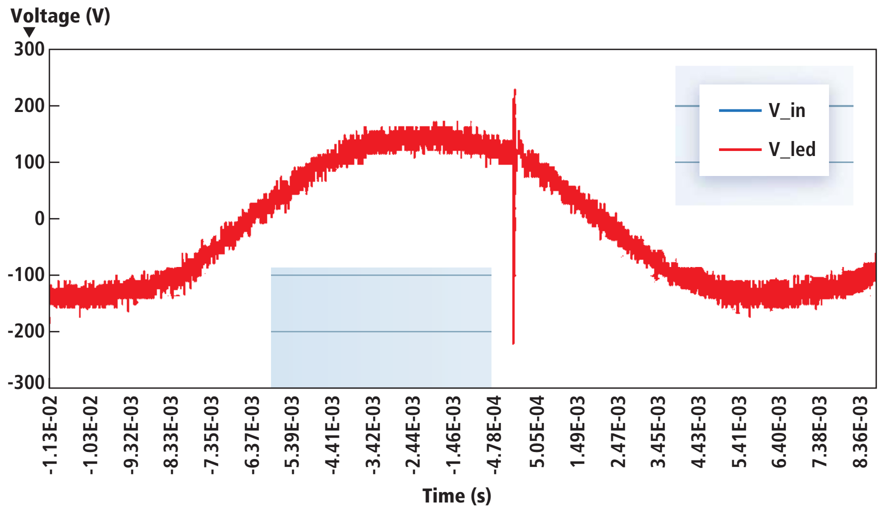

FIG. 3. AN3211 voltage response in a 2.5-kV 100-kHz ring-wave test.

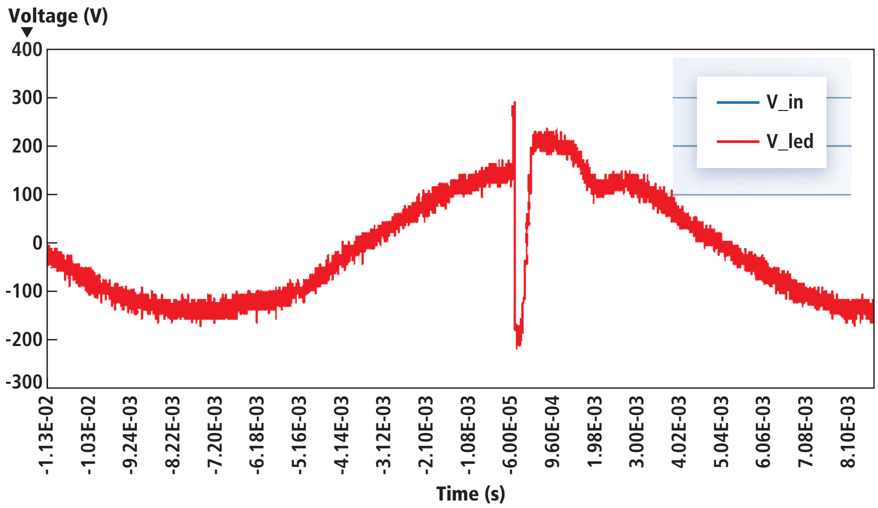

FIG. 4. AN3211 voltage response with a 7-mm, 200V MOV providing protection in a 8/20μs lightning surge test.

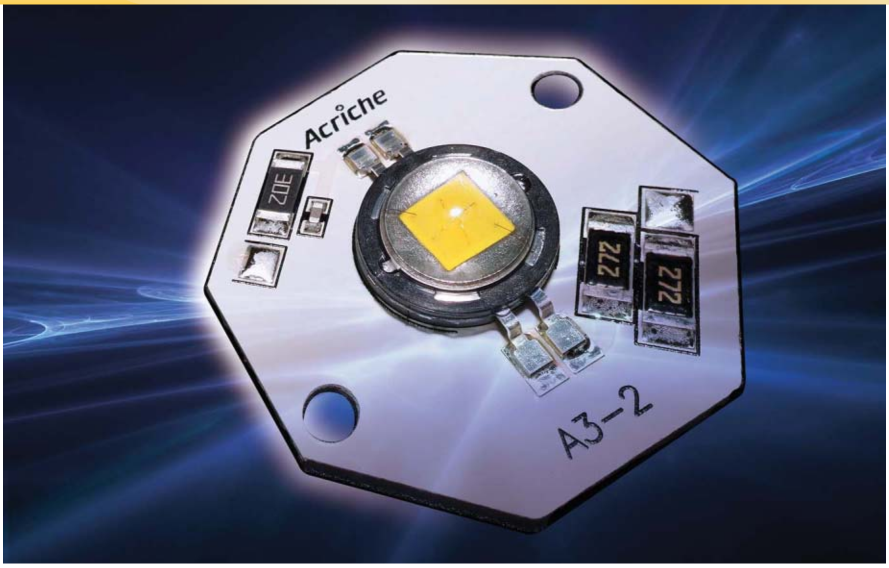

FIG. 5. Seoul Semiconductor A3211 AC-LED

a disproportionate change in current and affect light output, so the LEDs must be protected from these AC-line-voltage fluctuations. MOVs provide the primary transient over-voltage suppression in AC-line-voltage applications and help prevent transient overvoltage damage. The PPTC device helps limit the current flowing through the LED during steady-state over-current operation and helps protect it from voltage fluctuations.

Fig. 3 and Fig. 4 show test results on the AN3211 protected with a 7-mm, 200V MOV when lightning and ring-wave tests are applied to the lighting circuit. As seen from the results, the MOV solves lightning and ring-wave issues by damping the surges. Also, the light output is very stable during lightning surge and ring-wave testing. This approach helps equipment remain operational after specified lightning tests according to IEC 61000-4-5 and ring-wave tests according to IEEEC.62.41.

AC-LEDs have been used increasingly in general-purpose Illumination systems for indoor and outdoor use. Although the AC systems offer excellent reliability and design benefits, they also require robust protection to meet safety and performance standards.

Design risk can be minimized by pairing a PPTC over-current/over-temperature protection device with an MOV to provide a completely-resettable and coordinated circuit-protection solution. New products in development by Seoul Semiconductor include over-current, over-voltage and over-temperature protection provided by TE Circuit Protection's AC 2Pro device. This hybrid device combines a PPTC element with an MOV in one thermally-protected device, and gives designers flexibility and the convenience of integrated protection in a single device.

LED lighting allows companies to go green and save money

Green initiatives are certainly worthwhile given the positive impact on the environment, and LED lighting is one green technology that can also save companies and individuals money, explains **RON LUSK**, CEO of **LUMETECH GROUP**.

Environmental issues are not typically associated with maximizing the profits of big business. With the advent of LED-based solid-state lighting (SSL), however, companies and individuals can slash greenhouse-gas emissions while positively impacting the financial bottom line. Indeed, while LED lighting costs more than other technologies, savings in energy and maintenance costs more than cover the upfront premium. And with LED lighting dropping in price, SSL becomes more of a bargain every day.

Some green technologies have created more problems than they have solved. Ironically, the push for replacing incandescent light bulbs with lower-wattage compact-fluorescent lamps (CFLs) – thereby reducing consumption of electricity and the fossil fuels needed to produce it – brought its own set of environmental problems.

The supposedly green, environmentally-friendly CFLs contain mercury, albeit a small amount. However, if they are not handled or disposed of properly, CFLs can leach deadly compounds into the air and water supply, as well as contaminating landfills. A fact sheet about CFLs from the US Environmental Protection Agency notes that, "Exposure to mercury, a toxic metal, can affect our brain, spinal cord, kidneys and liver, causing symptoms such as trembling hands, memory loss, and difficulty moving." It goes on to add that, "Mercury is released into our environment when products with mercury are broken, disposed of improperly, or incinerated. If you break a CFL, clean it up safely."

Many states, cities and counties have outlawed the disposal of CFLs in the trash. Does anyone actually believe that CFLs survive intact in a landfill after a bulldozer has compacted the load into place? This assumes, of course, that a CFL actually arrives at a landfill in one piece.

LED lighting, conversely, is poised to deliver on energy savings with a positive environmental impact. With LEDs, businesses can reduce costs and not have to be concerned about proper disposal because the lights can be recycled.

Given the incredibly useful life of LEDs, recycling won't happen very often. With a minimum life of 50,000 hours, LEDs last five times longer than their nearest competitors. When compared with incandescent lamps (average life of 2,000 hours) the disparity is even more remarkable. Given their solid-state circuitry, LEDs are very durable. It takes a lot more than accidentally dropping or hitting an LED light to render it inoperable.

One of the major advantages of LEDs is that they can be placed in hard-to-reach locations that are sometimes accessible only with special lifts or scaffolding. Once in place, it will be years before these lights will need to be changed. Often, businesses wait until the number of burned-out light bulbs reaches critical mass before making replacements. And then, usually, all of the bulbs, including those that are still working, are replaced at the same time. The longevity aspect of LEDs can save businesses thousands of dollars in maintenance costs, not to mention operating costs from reduced electricity usage.

The decrease in electricity usage can actually have a double benefit in some situations. LED lights are often eligible for rebates and other cash incentives provided by governmental agencies and public utilities, thereby greatly reducing their cost of ownership. Another economic advantage of LED lighting for businesses is that due to their long lives, the initial cost can be capitalized on a company's balance sheet and depreciated over a period of five to ten years. This is an important feature for publicly-traded companies because it can significantly decrease operating costs which, of course, increases reported net income.

The reduction in energy use has another benefit. As less electricity must be produced, less coal must be burned in coal-fired power plants to supply that electricity. A significant amount of electricity produced in the United States comes from burning coal. This means that as less electricity is used, less coal is burned, and therefore less carbon dioxide (a greenhouse gas), sulfur dioxide, nitrous oxides, and mercury are emitted to the environment. As a result, installation of LEDs leads to less pollution and a lower carbon footprint.

LEDs are good for the environment and good for business.