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TECHNOLOGY AND APPLICATIONS OF LIGHT EMITTING DIODES

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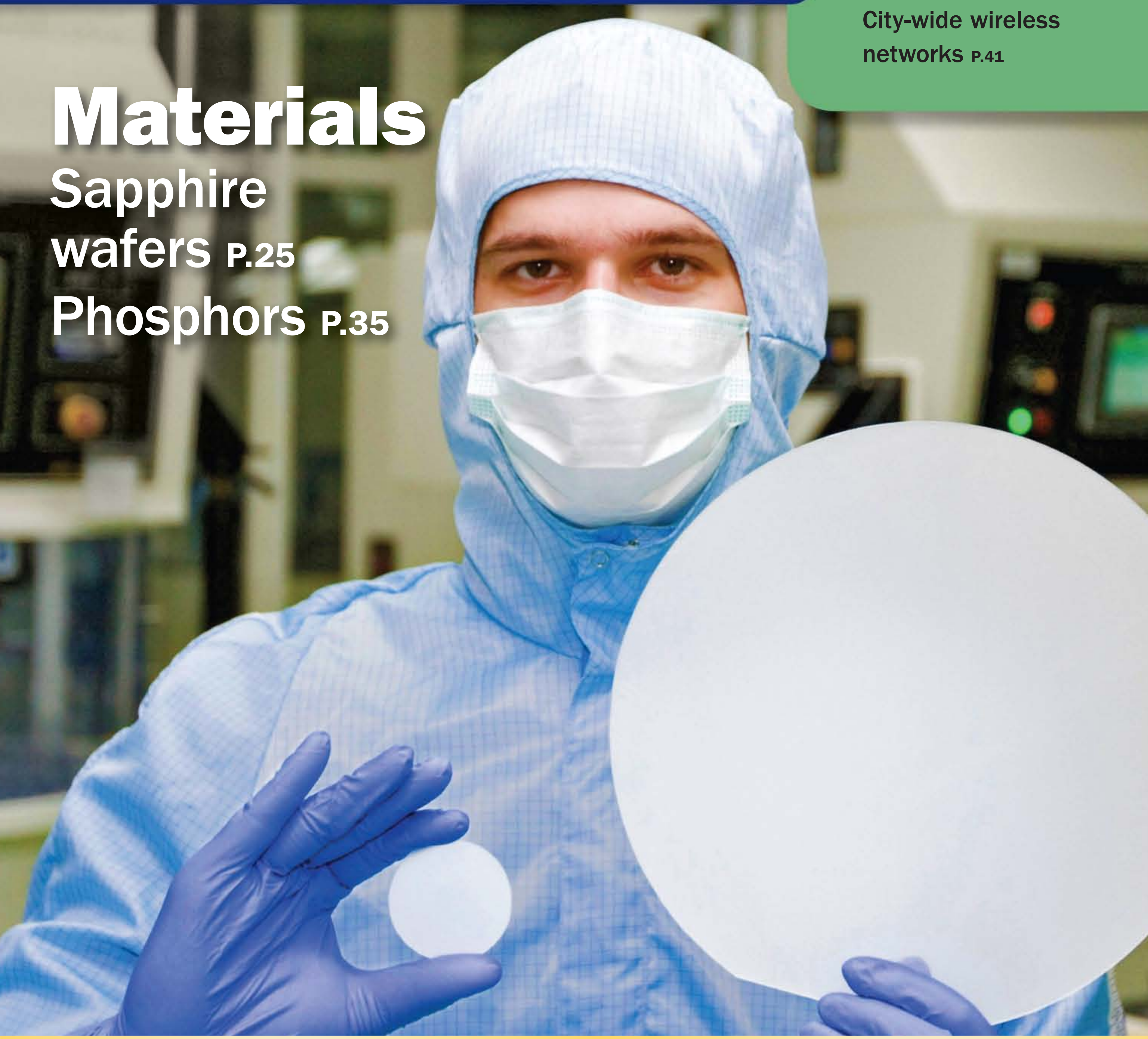

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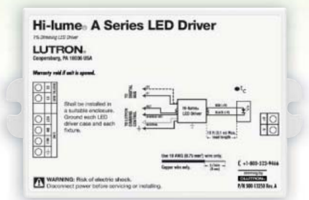

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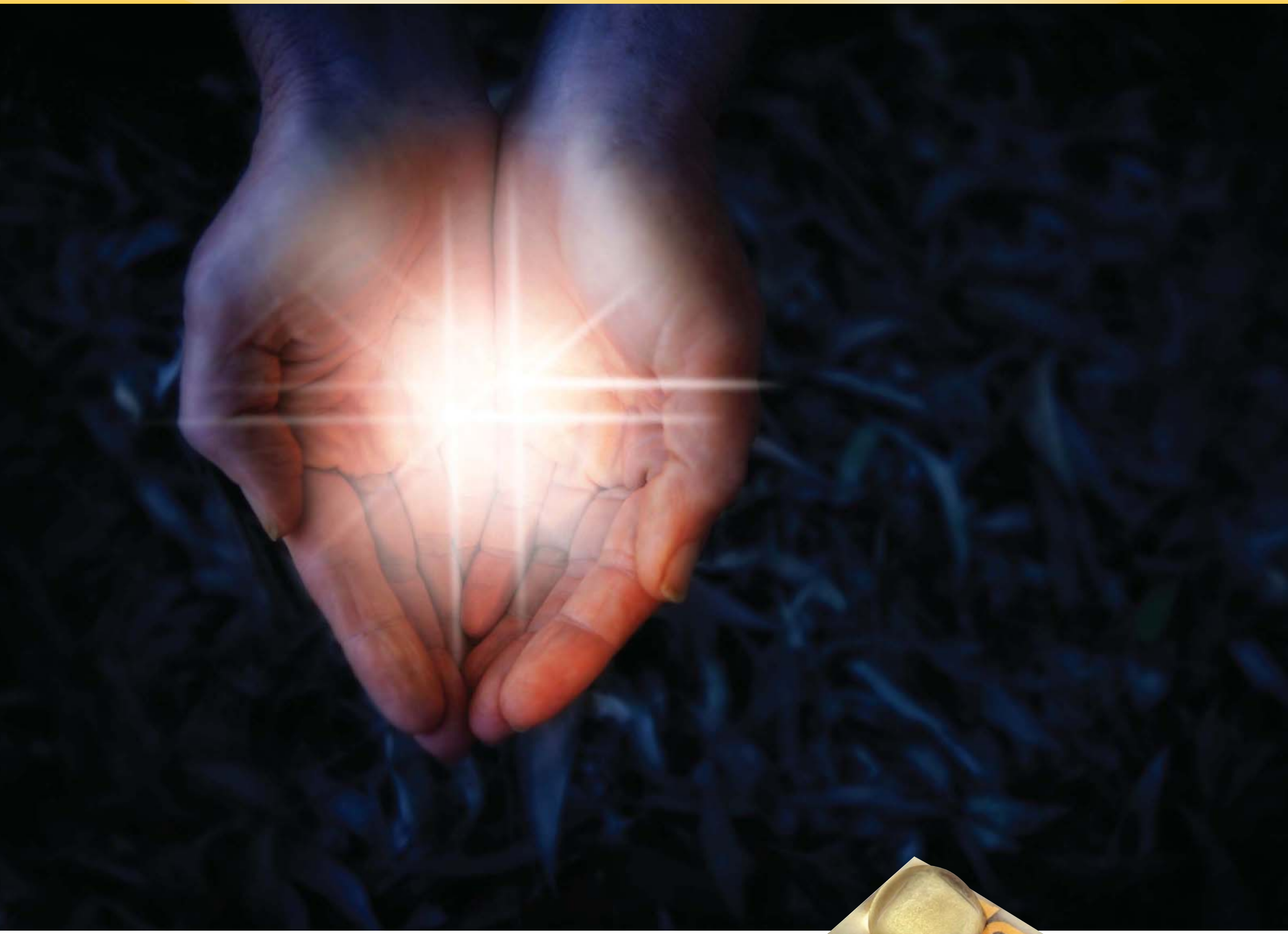

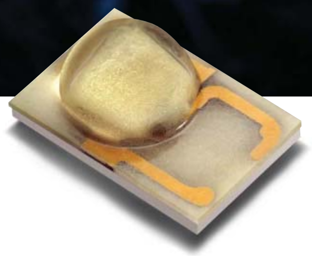

LEDs MAGAZINE®

ISSUE 40

february 2011

Cover Story

Sapphire wafer growers are adding capacity and LED makers are starting to work with larger wafers (see page 25). Our cover image shows a 10-inch sapphire wafer grown by Monocrystal.

features

columns/departments

commentary

Materials prove critical for LED suppliers

As this issue was being finalized, we learned that Rubicon Technology, a sapphire-wafer maker, has demonstrated a 12-inch sapphire wafer (www.ledsmagazine.com/news/8/1/23). While it's going to be a long time before we see LEDs produced on such giant substrates, it is certainly the case that a number of LED makers are already making the leap to 6-inch sapphire, with LG Innotek in Korea leading the charge. As reported on page 9, Philips Lumileds says it is making millions of power LEDs per week on 150-mm wafers, while Taiwan's Lextar has also talked about its R&D progress in this area. Cree is building a 150-mm wafer fab, and it seems certain that many other LED makers are also considering the move.

Due to a recent imbalance of supply and demand, 2-inch and 4-inch sapphire wafers are on a par in terms of cost per unit area (see page 25), although 6-inch sapphire remains significantly more expensive. This provides an incentive for LED makers to move to 4-inch wafers, and the wafer makers are installing capacity to be ready with suitably-priced material as demand for larger wafers continues to increase.

Larger wafers are just one way in which LED makers can, potentially, reduce manufacturing costs in order to achieve the targets that will result in large-scale penetration of the general lighting market. As the article on page 29 explains, reduced packaged-LED costs will come from manufacturing efficiencies that result from economies of scale and improved yields, and also from advances in technology for epitaxy, phosphors and packaging.

Just as sapphire wafers are critical for most GaN-based LED chip producers, phosphors are critical materials for white-LED manufacturers. Most LED phosphors contain rare-earth elements, and most of this material originates in China. As explained in our article on page 35, the new export quotas for rare-earth materials could cause a few headaches for companies that don't have a steady supply. And there are no quotas for internal consumption of rare earths within China, which could be yet another reason for LED makers to build fabs on the mainland.

Another critical group of materials are the metal-organic (MO) precursors used in MOCVD growth, particularly trimethyl gallium. The recent rapid growth in demand from the LED backlighting sector appears to have caused some tightness in demand, with consequent price increases. However, major MO suppliers have accelerated their plans to increase their capacity, and should be able to meet the anticipated level of demand as the LED industry continues to grow (www.ledsmagazine.com/features/8/2/2).

Outdoor lighting also features strongly in this issue, with an article on how to select an appropriate technology to fit the specific application (page 17). Another looks at how wireless networks can enable city-wide control of LED street-lighting deployments (page 41). Also, a pilot outdoor-lighting study evaluates the real-world performance of LED lighting technology, marking the end result of a manufacturing supply chain that began with sapphire wafers, phosphors and other starting materials.

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Cree's CEO suggests quicker LED move into general lighting

www.ledsmagazine.com/features/7/12/12

Choosing between LED and HPS street lights

www.ledsmagazine.com/features/7/12/11

Compatibility Part 3: Applying compatibility concepts to today's lighting products

www.ledsmagazine.com/features/7/12/9

Getting the light right: Sourcing the correct LEDs for the job

www.ledsmagazine.com/features/7/12/8

FEATURED *content*

strategically speaking

Strategically Speaking:

How many MOCVD reactors is too many?

An unprecedented level of orders for MOCVD reactors could create a glut in the LED market, but is unlikely to have much effect on high-end LED suppliers, says TOM HAUSKEN and Strategies Unlimited staff.

www.ledsmagazine.com/features/8/1/3

White Paper:

Halogen desk lamp conversion to LEDs

This paper describes a solution that has been specifically designed to exceed the residential Energy Star Power Factor (PF) requirements with minimal components and comparable light output to standard halogen-bulb solutions. Authors: JIM YOUNG and BERNIE WEIR, ON Semiconductor.

www.ledsmagazine.com/whitepapers/1

ADVERTISERS *index*

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· Applications: LED indoor Lighting, Office lighting, LED electronic display
PLC series 30W - 96W
· 90% High Efficiency / PFC / Class 2
· Applications: LED indoor lighting, Office lighting, LED electronic display
ELN series 30W - 60W
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· PFC / U bracket / 277VAC
· Applications: LED streetlamp (built-in type), LED indoor lighting
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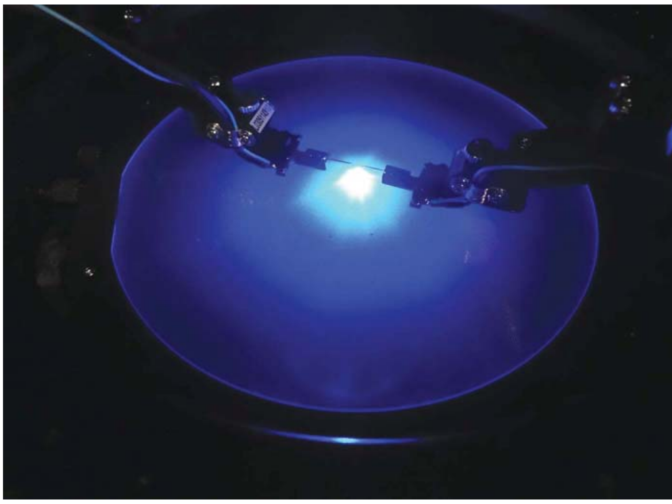
CHIP MANUFACTURING

Lumileds, Lextar look at 6-inch LED wafers


Source: Lextar Electronics Corp.

As LED manufacturers seek to increase capacity and yield and reduce cost, moving to larger-diameter wafers is seen as a key enabling step. While many LED manufacturers continue to use 2-inch wafers as the starting point for device fabrication, an increasing number already use 3- and 4-inch wafers. The next step is to transfer production to 150 mm (approx. 6-inch) wafers.

Philips Lumileds recently claimed (www.ledsmagazine.com/news/7/12/13) that it is "the first power-LED manufacturer in mass production on 150 mm wafers." The company, which has wafer fabs in San Jose, California, and Singapore, says it is now producing "millions of GaN-based LEDs weekly" on the larger substrates.

Lumileds says it will continue its current wafer production while ramping production of its 150-mm capacity to meet increasing demand from the lighting, automotive, and consumer electronics segments. The company pointed out that the addition of new epitaxy systems running 150-mm wafers represents a lower capital expenditure to achieve the same capacity expansion compared with adding a larger number of systems that run with smaller wafers.

LG Innotek is thought to be the first com- » page 10

RUSSIA

Optogan opens largest LED production plant in Eastern Europe

The Optogan Group of Companies, a Russia-based LED manufacturer, has opened a new manufacturing plant in St. Petersburg, Russia, which has benefited from an overall investment of 3.35 billion rubles (around EUR 80 million).

The facility, which is the largest LED component and module factory in the Eastern Europe and CIS region, was opened in late November 2010 by Sergey Ivanov, Deputy Prime Minister of the Russian Federation.

The factory will employ up to 800 people and covers 15,000 m^2 of floor space, of which 5000 m^2 is taken up by a clean-room environment. The first production line has an » page 10

CHIP MANUFACTURING

Cree opens China fab, shares take a tumble

A grand opening ceremony was held on December 8, 2010 for Cree Huizhou Solid State Lighting Co., Ltd. at the Huizhou Zhongkai High-tech Industrial Development Zone in Huizhou City, Guangdong, PR China (www.ledsmagazine.com/news/7/12/7). The facility is Cree's first LED chip manufacturing base outside North America, and this also makes Cree the first international LED company to set up a chip-manufacturing facility in China.

After Cree signed an agreement with Huizhou in November 2009, the factory was completed and put into production in just 8 months. The facility undertakes LED wafer cutting, testing and classification prior to packaging. Cree chairman & CEO Chuck Swoboda said that currently more than 50% of Cree's employees are working and living in Huizhou. "We have committed that in the coming 3-5 years, we will » page 10

news+views

6-inch from page 9

pany to have started making LEDs (specifically mid-power LEDs for LCD backlighting applications) on 6-inch wafers. Sapphire-wafer maker Rubicon has an ongoing contract to supply LG Innotek with 6-inch sapphire wafers. Also, Cree is building a new 150-mm LED wafer production facility in Research Triangle Park (RTP), and expects to have the first qualified products within the first half of this year.

Meanwhile, Lextar Electronics has claimed to be the first LED maker in Taiwan to demonstrate blue-light emission from a processed 6-inch LED wafer (www.ledsmagazine.com/news/8/1/7). Lextar says it has employed "unique exposure and grinding technology [to] avoid the issue of wafer warp and crack, which is the most challenging [issue] in 6-inch chip processing." Lextar is part of the BenQ Group, along with LCD panel maker AU Optronics. ◂

Cree from page 9

continue to expand our operation in Huizhou," he said. Swoboda also described Cree's development strategy as "Cree Chip, China Heart."

Lower-than-expected sales to Cree's LED component distributors in Asia caused the company's revenue to drop below analysts' expectations for the quarter ended December 26, 2010 (www.ledsmagazine.com/news/8/1/14). This caused Cree's shares to drop sharply by around 15% when the announcement was made mid January. Cree said the underlying cause was a pause in LED street-light demand in China, coupled with lower-than-expected growth in LED bulb applications. The company's revenue from LED products was $229.7 million, down 6% from the previous quarter, but up 26% compared with the same period last year.

Swoboda explained that the street-light slowdown in China was related to a pause in the market as new specifications were being developed by the government. Meanwhile, the LED bulb slowdown is related to Cree's customers working off inventory that was bought in the previous quarter ahead of end-customer demand.

Cree also announced a prototype 60-W-replacement LED lamp that can meet Energy Star performance requirements. The dimmable bulb uses remote-phosphor technology and delivers more than 800 lumens, consumes fewer than 10W and features a CRI of 90 at a warm-white 2700K color (www.ledsmagazine.com/news/8/1/25). ◂

Russia from page 9

annual capacity of 360 million LEDs, and further capacity extensions are scheduled.

This is the latest and largest example of investment and state support for the LED market in Russia. Also, a Non-Profit

Association of Russian LED Manufacturers has been formed by Optogan and Svetlana Optoelectronics (www.ledsmagazine.com/news/7/10/28). Optogan says that it has "found a suitable legislative and infrastructural environment to establish high-tech manufacturing in Russia to enabling high-volume LED output at competitive costs." Rusnano, the state fund providing investment for technology projects, is one of the company's largest shareholders. Optogan was founded in 2004 in Helsinki, Finland, by three Russian scientists. The company was acquired in late 2008 by Onexim Group, a private investment fund which is Optogan's major shareholder. ◂

MORE: www.ledsmagazine.com/news/7/11/29

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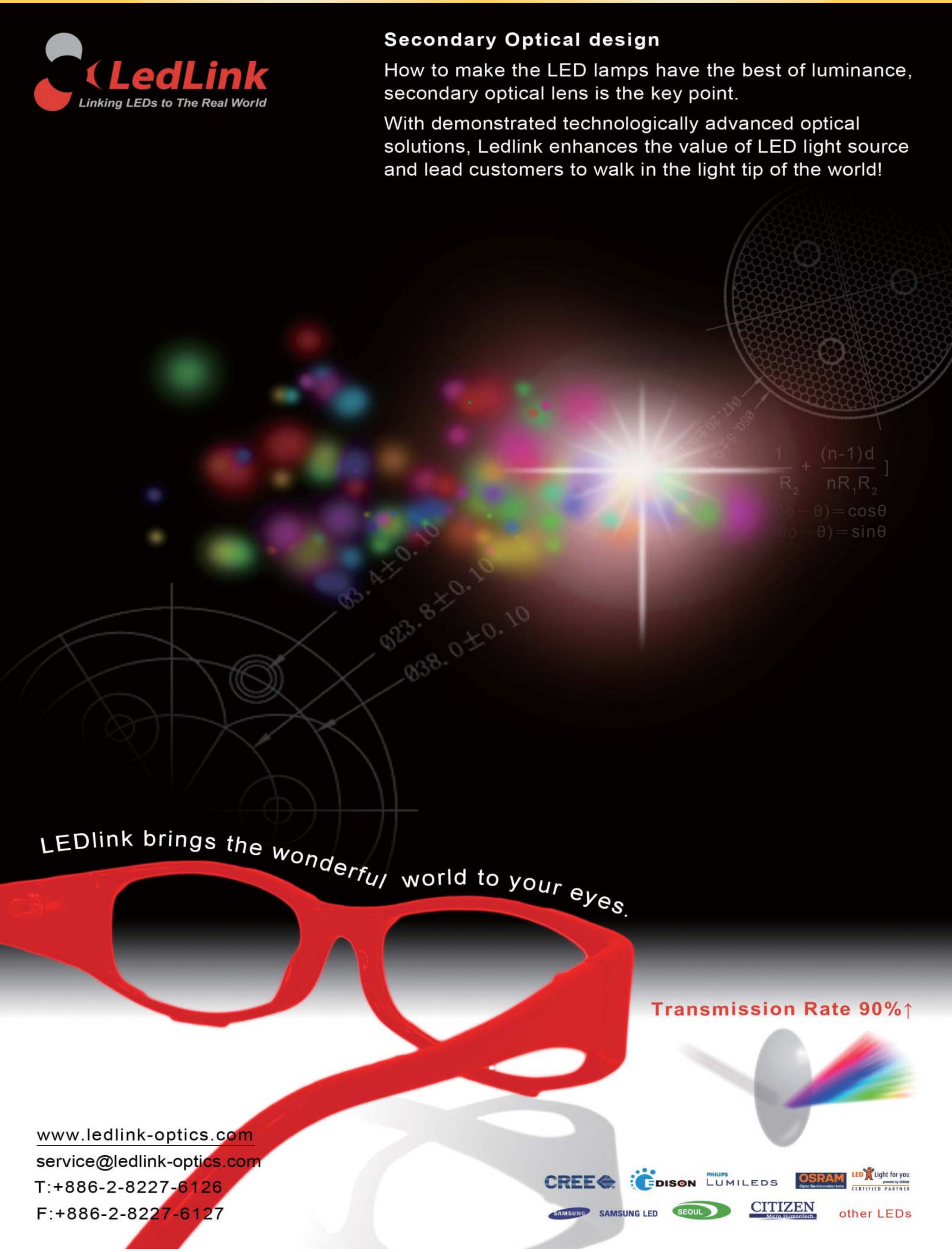
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STANDARDS

SEMI forms HB-LED standards committee

The industry association SEMI has formed an HB-LED Standards Committee with the goal of developing manufacturing standards. These are intended to eliminate unnecessary costs, and facilitate innovation in equipment and processes. Task Forces on wafers (initially focused on sapphire), wafer carriers, assembly and automation have already been initiated. Participants include key equipment and materials suppliers and have expertise in HB-LED devices, sapphire wafers and MOCVD wafer processing. Industry analysts expect a 10- to 20-fold decrease in costs over the next five years is needed to achieve rapid penetration of solid-state lighting into commercial and residential lighting applications. The SEMI HB-LED Standards Committee has been formed to help reach those aggressive cost targets. ◄

MORE: www.ledsmagazine.com/news/7/11/19

TEST & MEASUREMENT

Instrument Systems wins LG order

LED maker LG Innotek has placed an order worth several million euros with Instrument Systems, the Munich, Germany-based test and measurement specialist. The order is for a large number of CAS 140CT-series array spectrometers, which LG will use for testing LED wafers in a production environment. The LEDs are for backlight units for LCD TV sets. Instrument Systems says that the spectrometers enable all relevant photometric and colorimetric parameters of LEDs, such as luminous flux and color coordinates, to be determined within milliseconds. In further news, Instrument Systems GmbH has appointed Richard Young, a specialist in light measurement, to help the company to continue expanding its expertise in LED metrology. ◄

MORE: www.ledsmagazine.com/news/8/1/18

EVENTS

SIL Europe 2011 issues Call for Papers

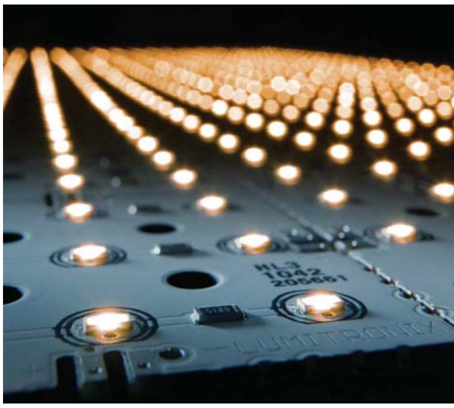
Strategies in Light Europe 2011 takes place on October 4-6, 2011 in Milan, Italy, and has the theme "Improving the Quality and Performance of LED Lighting." The conference program will be a mixture of invited talks together with presentations submitted via the Call for Papers, which is now open. The submission deadline is **Friday 18th March**. ◄

MORE: www.ledsmagazine.com/features/8/1/1

DISTRIBUTION

Nichia appoints first-ever LED distributor

Nichia, the Japan-based LED maker, has broken with its own tradition by appointing its first-ever distribution partner for LED products. Lumitronix LED-Technik GmbH, based in Hechingen, Germany, became an official distributor for Nichia in Germany on January 1, 2011. Until now, Nichia has supplied its LEDs directly to end-use customers, without using distribution channels anywhere in the world. ◄



MORE: www.ledsmagazine.com/news/8/1/5

BUSINESS

LG Innotek, Zumtobel team up

The Zumtobel Group, an Austrian lighting company, and LG Innotek, a Korea-based LED manufacturer, have signed a cooperation agreement in the field of LEDs, with the aim of transferring the successful high-volume business in LED backlights for LCD screens to the field of professional lighting. The two companies say that they will each be contributing their respective expertise in terms of technology, applications and production. One important aspect will be the use of LEDs as point light-sources to produce flat-area lighting. ◄

MORE: www.ledsmagazine.com/news/7/12/12

LED LAMPS

Fire hazard causes recall for Eco-Story LED lamps

Eco-Story, an LED lamp supplier based in Portland, Maine, has released a product-safety recall for LED lamps that can pose a fire hazard when used without a Class II transformer. The recall affects about 42,000 units, and was voluntarily conducted by the firm in cooperation with the US Consumer Product Safety Commission (CPSC).

The LED lamps can overheat when used without a Class II transformer, posing a fire hazard. The CPSC said that the company has received two reports of overheated lamps, but no injuries have been reported.

The recall involves 12-volt LED lamps with UL number E316865. Manufactured in China, the lamps have been sold to commercial locations, primarily restaurants, from December 2007 through August 2010, for between $19 and $45. The lamps were not sold directly to consumers. The CPSC says that commercial locations should stop using this lamp immediately and contact Eco-Story for a free replacement lamp which does not require a Class II transformer. ◄

MORE: www.ledsmagazine.com/news/8/1/22

BUSINESS

PhotonStar LED takes over Enfis

PhotonStar LED Ltd, a UK-based LED lighting manufacturer, has conducted a reverse take-over of Enfis Group plc, a UK-based developer of LED arrays and drivers for lighting and industrial applications. Enfis has been listed on the AIM stock exchange since March 2007. The company changed its name to PhotonStar LED Group plc and was admitted to AIM in late December 2010.

PhotonStar intends to extend its product range by adding lighting fixtures for architectural and retail markets using Enfis Group arrays and drivers. Enfis will continue to focus on the supply of arrays and light engines to specialist sectors such as film and TV production lighting and UV curing. PhotonStar intends to drive development of a range of highly-integrated light engines and controls for use in general illumination based on a combination of its technology and Enfis array products. ◄

MORE: www.ledsmagazine.com/news/7/11/30

COMPETITIONS

DOE suspends PAR38 L Prize

The DOE has suspended the PAR38 portion of its L Prize competition, which is stimulating the development of LED-based replacements for halogen lamps. No submissions have been received to date. The DOE said it will apply "lessons learned" in the 60W-incandescent-replacement portion of the competition and reopen the PAR38 competition in May with modified criteria. ◄

MORE: www.ledsmagazine.com/news/8/1/6

funding + programs

California law begins US phase-out of incandescent lamps

A new federal law introduced on January 1, 2011 in California has implemented standards for the energy efficiency of incandescent light-bulbs sold in the state, and will, in time, effectively remove 100W incandescents from the shelves. The new regulation states that lamps manufactured on or after January 1, 2011 must use 28% less energy in order to provide the same amount of light (in lumens) as previously available from a 100-watt bulb. In other words, incandescent lamps must now be able to produce 1500-1600 lm with a maximum of 72W. This standard does not affect the existing supply of incandescent light bulbs stocked in retail stores, or to incandescent light bulbs already in use.

The law, resulting from the Energy Independence and Security Act of 2007 (EISA), is designed to reduce energy use and associated pollution and make the USA less dependent on foreign sources of energy. While the rest of the USA will adopt this standard on January 1, 2012, California was given authority to implement the national standards one year earlier.

It is estimated by the California Energy Commission (CEC) that the new regulation will avoid the sale of 10.5 million inefficient 100-watt bulbs in 2011, which would cost consumers $35.6 million in higher electricity bills. The regulation is technology-neutral, with the CEC promoting halogen lamps, compact fluorescent lamps (CFLs) and LED lamps as possible alternatives (www.energy.ca.gov/lightbulbs/lightbulb_faqs.html). A new standard covering 75W lamps will be introduced in California on January 1, 2012, and standards for 60W and 40W lamps will follow in 2013 (see Table). In all cases, the rest of the USA will follow one year behind.

Europe is already at the stage, since September 2010, of phasing out 75W incandescent lamps. Also, packaging regulations have been changed so that lumens will now feature prominently. Only lamps that fall into energy class A will be allowed to carry an "energy-saving lamp" designation, or to carry a value for the percentage energy saving compared with incandescents.

In related news, the Environmental Protection Agency (EPA) has released a revised series of recommendations on how to deal with broken CFLs in the home (www.epa.gov/cfl/cflcleanup.html). There's nothing too controversial or over the top; in summary you should ask people to leave the room, shut off the AC for a while and dispose of all the bits safely. ◂

MORE: www.ledsmagazine.com/news/8/1/2

Traditional wattage	New maximum wattage	Light output (lm)	Implementation date in California*
100	72	1490-2600	January 1, 2011
75	53	1050-1489	January 1, 2012
60	43	750-1049	January 1, 2013
40	29	310-749	January 1, 2013

*US-wide dates are one year later. Source: California Energy Commission.

EPA releases final draft of Energy Star Luminaires spec

The US Environmental Protection Agency (EPA) has released the Final Draft of the Energy Star Luminaires v1.0 specification. This now has an effective date of October 1, 2011. The spec is available from www.energystar.gov/luminaires, which also carries comments on Drafts 1 and 2 of the spec. The Luminaires v1.0 spec will replace the Residential Light Fixtures (RLF, v4.3) spec and the Solid State Lighting Luminaires (SSL, v1.2) spec.

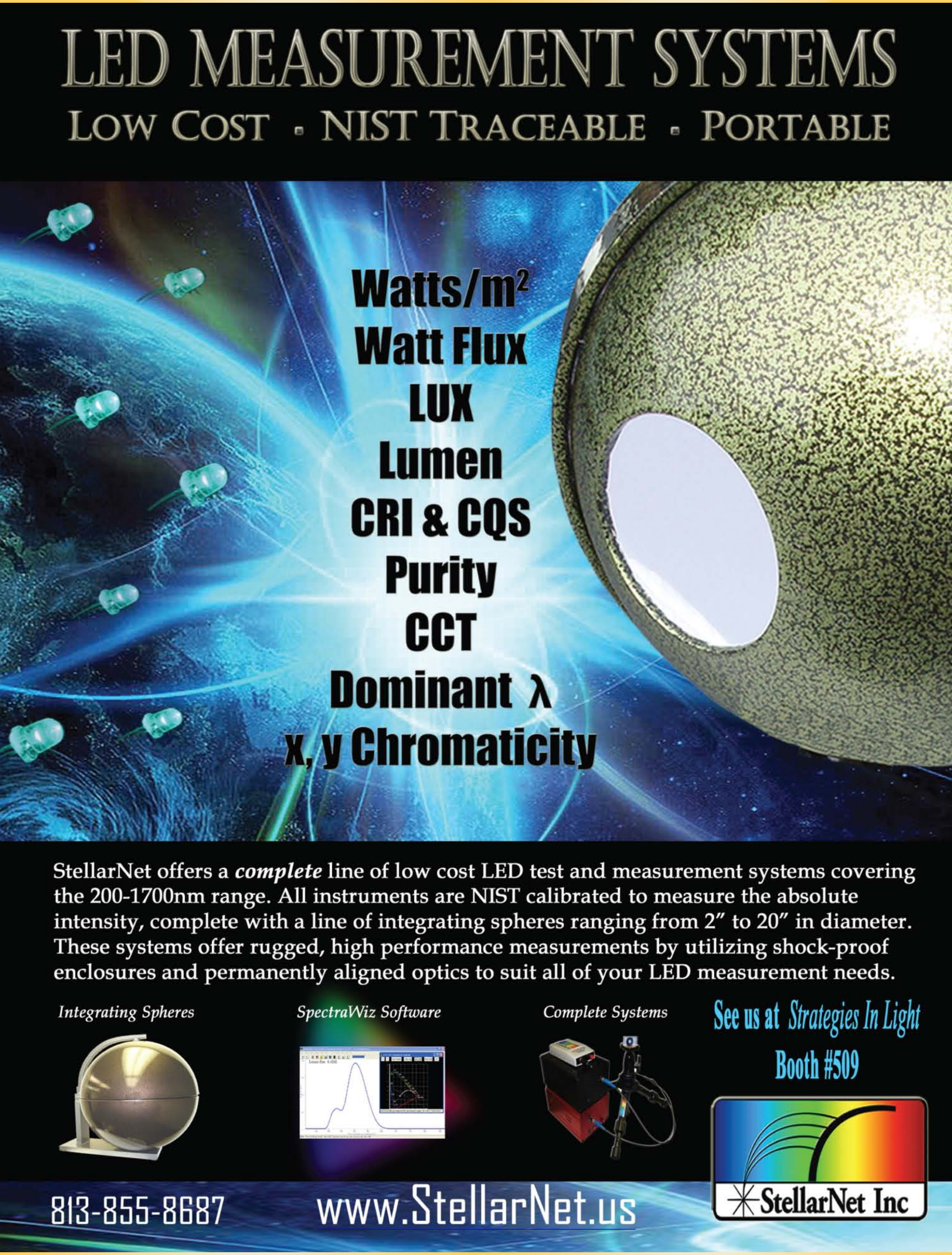
Among the modifications in the final draft, the power factor requirement was reduced to ≥ 0.5 for solid-state luminaires consuming 5 watts or less. This change reflects what is both broadly accessible and cost effective, says EPA. Also, accent lights and cove-mount luminaires, formerly included only in the residential scope, have been added to the commercial scope of the specification with the same performance requirements.

The modulation depth requirement detailed under operating frequency requirements for solid-state luminaires has been removed. EPA says it will continue to follow the work of various industry groups working to develop recommended practices to mitigate the potential for perceptible flicker and stroboscopic effects with this technology.

Luminaire models qualified prior to January 1, 2011 (or those submitted to EPA contractors prior to January 1 and subsequently qualified) will remain qualified until October 1, 2011. After this date, to remain on the Energy Star qualifying product list they must be certified by an EPA-recognized certification body to meet the Luminaires v1.0 specification requirements.

Luminaire models qualified after January 1 (i.e. certified by an EPA-recognized certification body) using the existing specifications and also meeting the Luminaires v1.0 specification requirements will be automatically added to the Luminaires v1.0 qualifying product list on October 1. ◂

MORE: www.ledsmagazine.com/news/7/12/14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Application requirements dictate best choice for outdoor-lighting technology

A methodology for evaluating lighting-design criteria and cost issues provides lighting professionals with a pathway to make the best outdoor lighting choices, explains **RONALD GELTEN**.

The introduction of high-power LEDs is causing nothing short of a revolution in professional lighting. New product generations are coming out every six months and new products are coming out from different vendors every day. New claims in efficiency, energy savings and longevity are made every month. People and organizations are calling for adjustments in lighting standards and legislation to accommodate this new technology. With so much going on, LEDs are taking up all the bandwidth and it is hard to keep track of what's true and what's real. It is all too easy to forget about conventional technologies which are also improving, in some cases faster than ever. Lighting designers need to carefully evaluate available technologies and application requirements to make the best outdoor lighting choices.

To get a basic grasp of the challenge lighting professionals face, consider the difficulty today of choosing a replacement for your dining room light bulb. Chances are that your old lamp was an incandescent and now you have all kinds of new options: halogen, or an energy-saving compact fluorescent lamp (CFL), or a retrofit LED lamp. The packaging on the lamp doesn't just show the wattage, it also talks about color temperature, lumen output, energy savings, and dollar savings per year or over the life of the lamp. After comparing all the numbers you take it to the next step and consider light distribution. Depending on the actual application, you may choose from a spiral-shaped CFL, a directional LED, an all-around LED, and others. Choosing a lamp now requires a bit more thought process.

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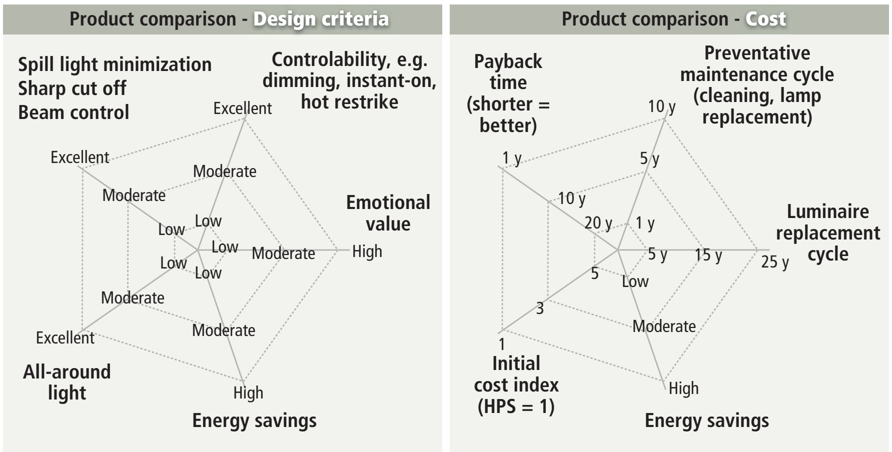

FIG. 1. Two examples of spider web diagrams. Left: comparison of several lighting design criteria. Right: comparison on various cost aspects.

Given the complexity, how does a lighting professional decide what it is best for an application? It is important to look at the main strengths of the dominant lighting technologies so you can make an educated choice. First you need to focus on the characteristics that are most important for applying the light sources, rather than focusing on in-depth technical attributes. In the end, it is all about choosing the right technology, for the right application and for the right reasons.

Let's consider outdoor lighting choices focused on today's three most prominent technologies – LEDs, high-intensity discharge (HID), and induction lamps. First we'll consider the attributes of each, and then how to compare the technologies. We'll cover the main strengths of the lighting technologies below and you will find a more detailed description online at www.ledsmagazine.com/features/8/2/1.

LED technology offers the following advantages:

- LEDs offer useful product lifetimes in the 50,000h range. When applied in confined spaces, such as indoor down-lights or incandescent retrofit bulbs, lifetimes are typically 20,000-30,000h. In large open spaces, such as in outdoor applications, longer lifetimes can be achieved.
- Efficacies for LEDs have hit the 100-lm/W range, with the bulk of LED products in the 50-80 lm/W range.
- LEDs excel in controllability such as dimming, instant-on, hot restrike, and varied color choices.

Some of the main strengths and current status of **HID technology** are:

- In terms of efficiency, the bulk of HID products produce around 100 lm/W. Top-line products are around 120 lm/W. Several companies have announced initiatives to bring efficiency to 150 lm/W.
- Lifetimes of HID systems are typically around 15,000h for low wattage lamps (below 100W) and up to 30,000h for higher wattage versions, with some companies

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planning to reach 40,000h.

• HID lamps are relatively low in cost and therefore offer short payback times of 1-3 years. There are retrofit solutions that offer 15-20% energy savings with a simple lamp replacement as well as system retrofit packages for various luminaires that allow higher energy savings of up to 50%.

Induction lighting can be viewed as a special form of fluorescent lighting. Some of the main strengths and status of **fluorescent** technology are:

• Lamp efficacies of 100-110 lm/W are common. Small incremental improvements in efficacy are continuously introduced. Induction systems are less efficient offering 70-80 lm/W.

• Fluorescent lamps with lifetimes above 40,000h are widely available, and induction lamps can last up to 100,000h.

• Fluorescent systems are offered at the lowest initial cost of all high-efficacy products.

Making the right choice

When it comes time to make a detailed comparison of the technologies, you can easily get lost in the details. Take time to assess the lighting requirements. Is there a special atmosphere that the customer is looking to create? How is the area going to be used, how will we coordinate the lighting with the planned activities? What are legislative requirements on wattage per square foot?

Then there are additional requirements, for instance: Is the customer interested in saving energy or in the shortest payback time? Is the installation easily accessible for maintenance? And your list may include other requirements. Based on those considerations we need to evaluate the different technologies and the various products within those technologies.

You can simply list the properties and performances of the various technologies or products in a table, and use that table to compare parameters like: efficacy, lifetime, mean lumen level, initial cost, payback time etc. There are two drawbacks to this method. First, the tables tend to get big which makes it is easy to get lost in the numbers. And second, it is not a very suitable method to communicate to the end user. I therefore propose an alternative method.

A 5-criteria comparison methodology

We start by picking the top-5 criteria for the lighting design and determine a scale for each of these. The top-5 criteria are then plotted in a spider web diagram. Fig. 1 illustrates two examples. In the left diagram we have selected five design criteria. We have selected these for comparison of several lighting technologies without having a specific application or lighting design project in mind.

On the right side of Fig. 1 we have selected various cost aspects of the lighting installation. Note that two parameters, payback time and initial cost index, are scaled backwards. This is so that the performance indicator is consistently better when moving away from the center of the spider web.

We will now populate the diagrams with a comparison of the three most important technologies for outdoor lighting: LED, induction and HID (for example ceramic metal halide). These three white light technologies are frequently used to replace existing high-pressure-sodium (HPS) or quartz-metal-halide installations.

LEDs design and cost criteria

The scores for LED systems are illustrated in Fig. 2. We will discuss the design criteria (left diagram in Fig. 2) first.

Beam control. Minimization of spill light is important for many applications and can help reduce wattage, limit light trespass or create drama. The directionality of the individual LED chips allows LED luminaires to excel in beam control and minimizing spill light.

Controllability. Instant-on and hot restrike can be related to convenience and safety. Dimming is mainly used for energy saving. Other forms of controllability, such as color variation, are used for creating drama and attracting attention. On all these aspects, LEDs are as good as any other technology and often better.

Inferred/Perceived value. Some lighting installations are purely functional but in many cases the inferred aspects come into play in the design and choice of the light source. LEDs are the latest technology with a phenomenal rate of improvement and therefore have a perceived value in creating a cutting-edge, modern image.

Energy savings. Savings are determined by the light source's efficacy in combination with fixture efficiency. LED products have a high efficiency in comparison with incandescent products, but the bulk of LED products have a lower efficacy than HID or linear fluorescent products. On the other hand, the high optical efficiency of LEDs improves their efficiency rating. As a result, today's LED luminaires offer moderate-to-high energy savings.

The term "all-around light" is used here as an opposite to beam control. In some applications it is desired to spread the light like a sphere such as in acorn fixtures lighting a street in a city center. The light is supposed to light the sidewalks as well as the building facades to prevent an oppressive atmosphere

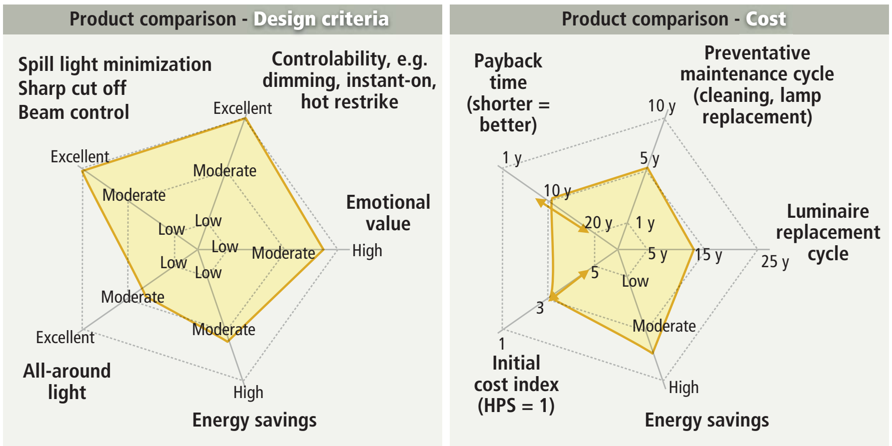

FIG. 2. Spider web diagrams populated with parameters of LED systems. Left: lighting design criteria. Right: cost aspects.

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in which people walk inside a tunnel of light. Another way to look at this is that spill light is actually useful in applications like this. If we want to spread light in all directions with LEDs, we require additional LED boards that radiate in different directions.

Now let's consider the various cost aspects of LEDs (right diagram in Fig. 2). For the purposes of this discussion, we will focus on the cost aspects at the luminaire level. For completely new installations, the overall cost is dominated by the poles and wiring rather than the cost of the luminaires (the heads on the poles).

Preventative maintenance. This is a topic of debate for LED systems. The long lifetimes of LED products suggest that maintenance costs are virtually eliminated. However, in outdoor applications, we can expect that some level of preventative maintenance may be required. Depending on the design of the LED fixture, lens cleaning may be required to maintain low lumen loss factors and heat sink cleaning may be required to obtain long lifetimes or to comply with warranty terms.

Luminaire replacement cycle. Almost all current LED products have non-replaceable LED parts. When the LEDs or their driver reach end of life, the entire fixture needs to be replaced. In some cases, the replacement cycle is shortened because the improvements in LED technology drive upgrades of

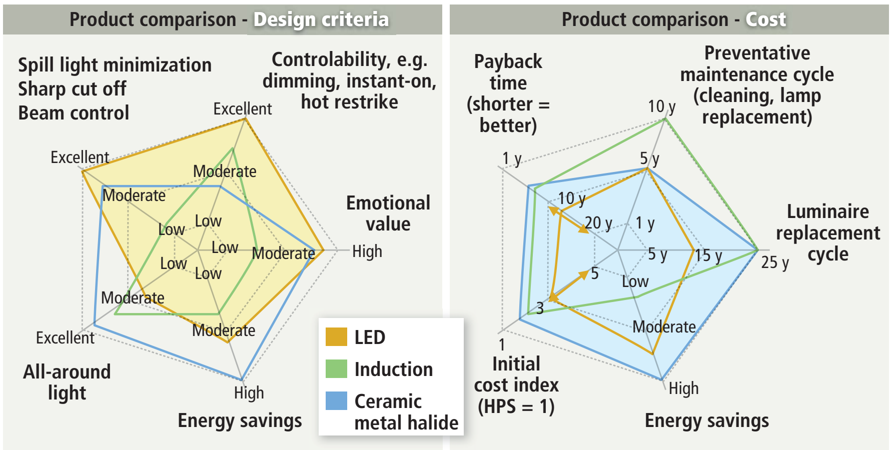

FIG. 3. Spider web comparisons of LED, induction and ceramic-metal-halide systems. Left: design criteria. Right: cost aspects.

the installation. There is an upcoming trend towards a modular approach in which the LED boards can be replaced at end of life or when upgrades become economically feasible. The availability of such solutions will increase in the coming years. Especially when combined with some level of standardization, we can expect the luminaire replacement cycle for LEDs to increase in the future.

Initial cost index. We have used HPS as a reference for initial cost index because this is the technology that is most often replaced. Generally speaking LED systems are 3-5 times more expensive than HPS systems of similar wattage or light output.

Payback time. LED systems show a great variation in payback depending on the technology that is being replaced and the LED products that are being used. Relatively short payback times of 3-8 years are achieved for installations where utility rebates or grants are included. Considering installations without rebates or grants, we see that most installations indicate payback times of 8-15 years.

Induction and metal halide lights

We will now add induction and ceramic metal halide to the discussion and to our spider diagram in Fig. 3. Examining the design

criteria diagram on the left we can make the following points.

Beam control and minimization of spill light with the compact ceramic-metal-halide sources is almost as good as with LEDs. LED systems enable the lowest light spill. On the other hand, fitted target efficacies are often higher with compact HID sources with optimized optics. HID sources without optics will spread the light in all directions in a spherical pattern, hence HID scores high on all-around lighting. The bulky shape of induction lamps limits the optical performance. On the other hand, induction scores quite high when spherical light distributions are required, especially for the bulb-shaped induction lamps. The traditional shape of a lamp makes such all-around light distributions easy.

Controllability of induction technology is good. The main reason that induction ranks below LEDs on this aspect is due to the lack of variable color support and spatial control or beam pattern. Ceramic metal halide scores much lower. Nowadays, there are dimmable metal-halide solutions available and even some ceramic metal halides that do not change color when dimmed. But controllability is certainly not a strength for HID light sources.

In terms of aesthetic value, ceramic metal halide scores high for its sparkle effect and crisp, high-quality light. Induction and other fluorescent sources are more functional light sources.

Energy savings are highest for ceramic metal halide because these light systems have the highest efficacy available today and because the latest compact metal-halide lamps allow for very high optical efficiencies. Induction efficacy is on par with the bulk of LED solutions, but LED scores higher due to its higher optical efficiency.

Cost aspects are shown on the right diagram in Fig. 3. Induction lighting is often installed in locations where maintenance costs are very high, such as tunnels. Preventative maintenance is usually not done in these locations, which is permitted by the reliability and longevity of the induction systems. Also in more accessible outdoor installations, preventative maintenance may not be necessary due to the low lumen loss factors of good-quality induction lamps. Despite the increased lifetimes on the most recent ceramic-metal-halide sources, preventative maintenance cycles are still around 5 years. There are luminaire solutions on the market which use 2 or more lamps in a fixture, thus doubling the lifetime for lamp replacement to 40,000 – 60,000h, but such solutions are rare.

Luminaire lifetimes for induction and HID is typically 20-35 years. Initial cost of induction and HID luminaires are 1.5-3 times higher than our reference HPS.

The combination of energy savings, initial cost and maintenance cost typically results in payback times of 2-5 years for ceramic metal halide and induction. ROI for ceramic metal halide installations is typically earned back

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Sapphire wafer supply and demand remain in the balance

Sapphire wafer prices rose sharply during 2010, particularly for 2-inch material, but crystal growers are adding capacity and LED makers are looking at larger wafers. **TIM WHITAKER** reports.

The vast majority of gallium nitride (GaN) based LED chips are made from semiconductor layers grown on sapphire wafers. In the previous 12 months, the price of 2-inch sapphire wafers has risen dramatically, for a variety of reasons. "Currently, the price per unit area of 2-inch is essentially on a par with 4-inch," says Eric Virey, an analyst with Yole Développement. "This provides LED makers with a significant improvement in cost-of-ownership for their MOCVD tools if they move to 4-inch, which can be a strong incentive to accelerate the switch."

Virey says that pricing for 2-inch sapphire in Q4 2010 ranged from around $24 to above $30, depending on buying power, compared with around $11 at the same time last year (see Fig. 2).

Sapphire suppliers such as US-based Rubicon Technology have reaped the benefits of recent price increases (see www.ledsmagazine.com/news/7/12/4). Raja Parvez, Rubicon's CEO, says that, during the market downturn in 2009, prices fell substantially to a level that was not sustainable from the point of view of sapphire suppliers. So in part the recent price rises are due to a market correction, but in part they are also due to an imbalance in supply and demand, particularly for 2-inch wafers. A massive amount of MOCVD growth capacity has been added recently, particularly in China and Taiwan, which has created strong demand for 2-inch sapphire. Also, some sapphire suppliers have promoted 4-inch wafers, and have increased their output of this product, which has in turn reduced the availability of 2-inch wafers.

Virey believes that supply and demand is roughly in balance right now, and that pricing may have reached a plateau. "I am expecting to see rapid [demand] growth again beginning in March, which will put some strain on the sapphire supply," he said. "On the other hand, so much new capacity is coming on line." This includes established tier-1 suppliers such as Rubicon or Russia-based Monocrystal, as well as relative newcomers such as Sapphire Technologies in Korea, which claims to have a higher production capacity than Rubicon. Also, a great deal of capacity is coming online in Taiwan, says Virey.

"Supply is still going to be a little tight in the first half of 2011, but I'm not expecting the price to go up any further," says Virey. "I believe in the second half of the year, when there is even more capacity available, prices will come down, and they should eventually stabilize around the $14-15 mark for a 2-inch epiready wafer."

FIG. 1. Raja Parvez, President and CEO of Rubicon Technology, and CFO William Weissman celebrate the first sapphire boule from the company's new Batavia, IL facility (www.ledsmagazine.com/news/7/12/4).

Sapphire supply chain

The supply chain for sapphire has several steps, beginning with crystal growth. The crystals, or boules, are drilled to produce a core of material with a circular cross-section. The cores are mapped, and areas with crystal defects are removed. The cores are sliced to form thin circular wafers, and these are polished to make them ready for epitaxial growth.

The supply constraint occurs at the crys-

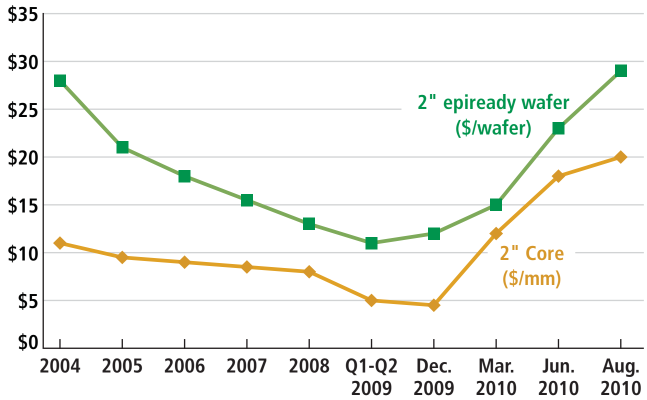

FIG. 2. Recent pricing trends for 2-inch sapphire core material, and wafers. (Epiready = material that can be used directly for epitaxial MOCVD growth). Source: Yole Développement.

tal growth stage, where suppliers must install additional furnaces in order to add capacity. Rubicon, for example, recently opened a new manufacturing facility in Batavia, Illinois, and is now filling this factory with new crystal growth furnaces. When fully fitted out, the new facility is expected to double Rubicon's capacity, which currently stands at 5 million 2-inch-equivalent wafers per year.

Like many other crystal growers, Rubicon makes its own proprietary equipment, understands the process and can qualify new furnaces relatively quickly. But furnaces are now also available as turnkey solutions from companies such as GT Solar, Thermal Technology and ARC Energy. In December 2010, for example, GT Solar announced large orders from two Chinese companies for growth furnaces (www.ledsmagazine.com/press/28616), while Thermal Technology launched a commercial kyropoulos crystal grower (www.ledsmagazine.com/press/28768).

But how long will it take to get these furnaces up and running? Depending on the company's experience and its infrastructure, says Virey, this could be anywhere from 6 months to 18 months. "It is certainly possible to enter the market more quickly than a few years ago, but it is still not a slam-dunk," he says. "A lot of companies are underestimating the time required."

A further consideration is the availability of raw materials for crystal growth; in the case of sapphire, this is high-grade (high-purity) alumina in a suitable form, such as pellets or microbeads. Virey says there are around 8-10 suppliers and pricing went up a little recently but there did not appear to be a supply shortage. "The key players are increasing capacity, so it looks like any issues will be resolved," he says.

Moving to 6-inch wafers

Most if not all major LED makers have considered the benefits and challenges of moving to 150-mm (approximately 6-inch) diameter sapphire wafers, but in most cases the move is not a certainty. "LED makers will only go to 6-inch if they can demonstrate clear advantage in terms of cost of ownership," says Virey.

Companies at the forefront of 6-inch wafer manufacturing include LG Innotek, which has placed a $71 million, 12-month order for 6-inch sapphire with Rubicon. However, LG is rumoured

to be having production issues using the larger wafers, and its output is not known. Philips Lumileds recently said it is producing "millions of GaN-based LEDs weekly" on 150-mm substrates at its wafer fabs in San Jose, California, and Singapore (www.ledsmagazine.com/news/7/12/13). Elsewhere, Lextar Electronics laid claim to be the first LED maker in Taiwan to demonstrate blue-light emission from a processed 6-inch-diameter LED wafer (www.ledsmagazine.com/news/8/1/7). Also, Cree is building a 150-mm wafer fab in North Carolina, and says that it is on track to have the first products qualified by the end of June 2011. Of course, Cree will use 150-mm silicon carbide, not sapphire.

Due to a lack of customers until recently, and a lack of specifications (especially thickness), there has been a wide diversity of pricing for 6-inch sapphire, in the $480-$600 range. Virey believes the sapphire makers have a lot of room to get their 6-inch prices right to hit the sweet spot for LED makers.

A 6-inch wafer has 9 times the area of a 2-inch wafer, but it is also much thicker, anywhere from 1.0 to 1.5 mm compared with

FIG. 3. Monocrystal recently demonstrated a 10-inch sapphire substrate (www.ledsmagazine.com/press/28724).

0.43 mm for a 2-inch wafer. This means that a 6-inch wafer can have a volume that is around 30 times larger than a 2-inch wafer, reducing the number of wafers per crystal. "Also, when you make larger wafers you have less flexibility to avoid defects when you are drilling the core, and this results in lower yield," says Virey.

Tier-1 crystal growers have an advantage because they can grow very large crystals and extract wafers with reasonable yield. For example, Rubicon has already demonstrated very large crystals weighing 85 kg (see Fig. 1). Meanwhile, Monocrystal recently announced availability of ultra-large 10-inch c-plane epi-ready sapphire substrates (see Fig. 3). However, it seems unlikely we will see LED makers using these wafers in production any time soon.

HB-LED manufacturing technology looks on track to meet cost demands of general lighting market

Technical breakthroughs and manufacturing improvements should keep the LED industry on track to improve performance and reduce costs at an appropriate rate, but this is not a done deal, as **ERIC VIREY**, **PHILIPPE ROUSSEL**, **PAULA DOE** and **TOM PEARSALL** describe.

In the booming HB-LED market, it's easy to forget that the next wave of growth depends on technology that doesn't actually exist yet. Development of a volume market for general LED lighting depends on technical breakthroughs and manufacturing improvements that reduce costs per lumen by as much as a 10x, in order to compete with fluorescents. But recent progress suggests the industry looks on track to meet the challenge.

Strong demand for display backlights propelled the HB-LED sector to better than 50% growth in 2010, and 2011 will likely see another 50% jump. Displays should continue to drive double-digit growth through 2013-2014. However, as the displays sector matures, continued growth will be dependent on the quick development of significant demand for general LED lighting by 2015. Based on our assessment of recent progress towards improving performance and reducing costs, we think the industry is on track to achieve this. But it's not a done deal: there's a lot more development that needs to happen.

"If this industry is going to continue to grow, it will be with general lighting," says Tom Pearsall, Secretary General of the European Photonics Industry Consortium (EPIC). "And that depends on continued major progress in everything from basic research and materials to device design and manufacturing efficiency. If LEDs remain even 2x to 3x more expensive than CFLs, then the curve won't look so pretty. Bringing down these costs is still a big challenge, not like a red carpet that will just roll out. There's still real opportunity for disruptive discoveries."

EPIC Consortium members identified a need for better information on these key manufacturing technology issues as their top priority. The organization commissioned a report entitled "LED Mantech" ("LED Manufacturing Technologies") from Yole Développement, and EPIC members worked with analysts on focus and content.

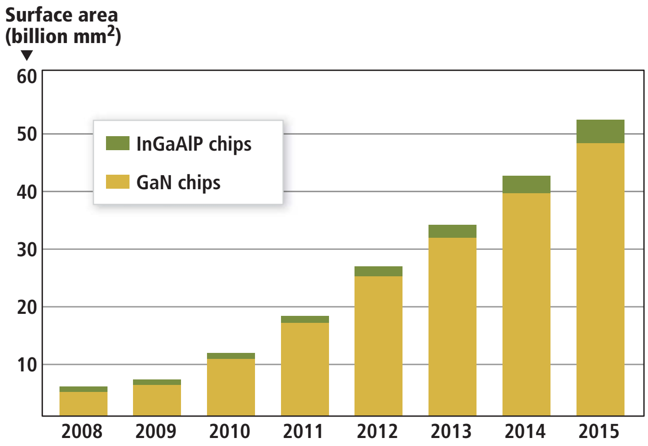

FIG. 1. Processed die surface area by material type. Source: LED Mantech 2010 report by EPIC and Yole Développement.

Economies of scale, improved yields

The best opportunities to reduce packaged LED costs will come from manufacturing efficiencies that result from economies of scale and improved yields, and from advances in the technology for epitaxy, phosphors and packaging.

Economies of scale typically drive down costs, and the HB-LED sector will certainly be churning out the volume. The compound annual growth rate (CAGR) in revenue of 28.2% through 2015 – our base scenario – will drive even faster growth in wafer volume and processed surface area. Steadily-declining average selling prices will mean that the $25.7 billion in LED sales in 2015 will require a more than 40% CAGR in processed surface area. Fig. 1 shows that the chip surface area will reach 51 billion mm^2 in 2015, eight times the area processed in 2009.

As manufacturing yields improve, wafer usage won't jump quite that much, but we still expect a seven-fold increase, or 37% CAGR, in wafer starts over the next five

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years, to 86.3 million two-inch wafer equivalents in 2015.

With these kinds of wafer volumes, the capacity needed to be a player in 2015 will be massive, and will require massive investment. Big, vertically-integrated companies are likely to be a major force, for example the integrated electronics companies Samsung and LG. Since entering the LED business two years ago, these companies already account for 20% of global die capacity, according to Yole's LED fab database. Semiconductor makers now getting into the LED business are also likely to be among the players able to invest for these kinds of volumes. Of the more than 60 companies now involved in epitaxy of GaN-based LEDs, only those who reach critical mass and master the technology will survive, so we expect considerable consolidation, starting in 2013.

Equipment suppliers

These kinds of volumes get the attention of IC equipment suppliers, who are now starting to invest in developing equipment specifically tailored to the LED sector's larger pattern dimensions, smaller wafers, and issues such as wafer bowing and transparency. Such equipment is better able to deliver higher yields and throughputs. As the sector moves from lab-like production to industrial-scale continuous processing, it will move to automated wafer-handling and computerized process control. Industry interoperability standards could help smooth the process. New entrants from the semiconductor industry, such as Samsung, TSMC, and Micron, could also accelerate this transition.

We expect that close to 1400 additional MOCVD reactors will be needed to meet LED demand in the 2010-2014 period. Also, the generous subsidies from the Chinese government, which will likely continue to some extent, may fund another 700-1000 more. This could create a short period of oversupply in late 2011; however, most of this excess capacity will be in the hands of newcomers with little manufacturing experience, so the impact will be mostly at the low end of the market. Even so, temporary shortages may also occur for some of the more demand-

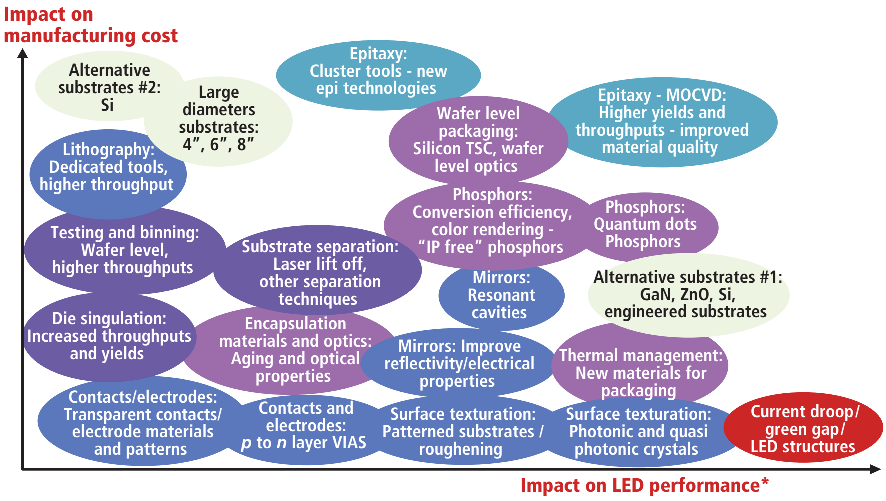

FIG. 2. Key technologies & research areas, showing relative impact in SSL cost of ownership. *LED performance includes efficiency, lumen/package, color rendering, lifetime. Source: LED Mantech 2010 report by EPIC and Yole Développement.

ing applications. With this booming market, MOCVD tool makers have invested seriously in improving performance, with the new generation of reactors getting twice the throughput of the older models. Suppliers target a 2x improvement in cost-of-ownership every 5 years.

Better equipment and the move to automated volume production will likely improve manufacturing yields. There is certainly plenty of headroom now, but the margins for improvement will narrow as the industry matures. We estimate that with the substrate edge-exclusion area, the cutting streets between dies, and the average process yields in epitaxy and packaging, currently only about 24% of processed substrate surface is turned into qualified dies (i.e. those that meet the specifications for a given application). The industry looks on track to increase yields to more than 40% by 2020 according to our base scenario. This relatively low level even a decade out is because significant improvements in yield will become more difficult to achieve as the technology improves and as specifications become much more stringent.

Larger wafers improve efficiency

The move to larger-diameter wafers will also help bring down costs. Though most production is still on 2-inch wafers, the mainstream is moving to 4-inch and the leaders are preparing to move to 6-inch wafers. The strong demand for LED backlights pushed demand for 2-inch sapphire wafers up faster than the supply, so 2-inch wafer prices rose to equal 4-inch prices in dollars per unit surface area. This pushed some companies to switch to 4-inch, enabling better throughput from MOCVD reactors and other process tools. Massive adoption of larger wafers will start in 2011, with 2-inch wafers dropping to less than 50% of total wafers processed for the first time.

The move to 6-inch inch wafers will likely improve process productivity significantly in the next few years. For example, Aixtron's new generation of 6-inch-wafer reactors can process a third more surface area per run. The 6-inch wafers still remain more expensive and in short supply, as there is limited capacity to produce high-quality sapphire in large crystal boules, so the main transition will likely not be for a year or two. But more capacity is coming on line this year, with Rubicon and Monocrystal doubling capacity, and Sapphire Tech in Korea now claiming to have capacity larger than Rubicon. LG started production on 6-inch wafers in 2010, and at least two more companies, Philips Lumileds and Lextar, are following close behind.

Companies are sampling 8-inch wafers, for production in 2012 or after, driven by the availability of good legacy 8-inch tools from the semiconductor industry. This has the potential to make production more efficient still, if the issues of growing the larger boules and dealing with the bow or thickness of the larger diameters – and the issue of cost – can be solved.

So far all the research on other substrate materials has yet to produce a clear alternative to sapphire, but the possibility remains of developing a disruptive substrate technology. The most promising alternative is silicon: although good devices can be made, costs are not yet competitive.

Packaging and phosphors

Encouraging developments in phosphors and packaging also seem likely to reduce costs in the next few years. We expect to see significant expansion in the use of silicon package substrates for better thermal management, opening the way to wafer-level packaging. If the die are redistributed across a package substrate wafer, then phosphors and lenses can be applied across the whole wafer, and interconnects and heat distribution added with through-silicon vias. This should significantly reduce assembly costs compared to assembling all the tiny die individually after dicing. Such technologies are already in use in MEMS, CMOS image sensors, and wafer-level camera-module optics, so much of the groundwork is already done.

There's also plenty of room to reduce the cost of the phosphors that convert the light to the desired white color, as patents expire, volumes increase, and manufacturing processes improve. Quantum dot technology is also a promising approach, but one still in its infancy, and more work is needed to further improve efficiency and stability and to develop cadmium-free compositions.

Sun and symbolism inspire disc-shaped LED spotlight

HARALD GRÜNDL of design studio **EOOS** discusses the design of Zumtobel's LED-based Discus spotlight, the shape of which mimics the sun's rays.

Zumtobel's Discus spotlight series was designed by EOOS, a Vienna, Austria-based design studio, which has been a long-standing partner of the lighting company. The design ensures purely passive cooling of the central LED module, in addition to very compact dimensions and a distinctive appearance.

The unmistakable shape of the Discus spotlight series reflects the familiar perception of the sun – a disc with radially-arranged rays. In this case, the "rays" are the blades of a passive cooling attachment, ensuring a long service life for the central high-performance LED module. With a depth of only 28 mm, the luminaire is extremely flat, and the compact, unobtrusive design of the track box adaptor conforms to the spotlight's minimalist nature. The spotlight series won an iF product design award in 2010.

As well as designing the Discus spotlight series, EOOS has designed Zumtobel products such as the Tempura LED spotlight, the Vivo LED spotlight and pendant luminaire and the Liviano "eco-design" spotlight. The company has a self-declared philosophy of Poetical Analysis, which essentially means that the design process is preceded by an exploration of the corporate philosophy of the partner, in an effort to understand the subconscious identity of the client, and hence to achieve a perfect balance of functional and emotional components. Poetical Analysis primarily involves the search for an intuitive image, a ritual, a story or a myth.

Harald Gründl, one of the founders of EOOS along with Gernot Bohmann and Martin Bergmann, has provided insight into the design considerations for the Discus product.

What challenges did you face during the development of the Discus spotlight series?

Harald Gründl: The idea of developing a really flat spotlight goes back four years to the briefing for our first LED spotlight (Tempura). The advances in LED technology, and the greatly increased efficiency of LEDs, have finally made it possible for us to realize our vision of developing a simple disc-shaped LED spotlight. This confirms our conviction that a technological change is really taking place – that the LED

FIG. 1. Harald Gründl, one of the creative heads of the Vienna-based design studio EOOS, discusses the creation of the Discus LED spotlight.

FIG. 2. The flat and unobtrusive shape of Discus allows integration in any architectural environment.

can actually meet the future requirements of lighting quality and energy efficiency. So far, LED technology has been integrated in conventional constructional shapes. During the development process we soon realised that we would do this the other way round and integrate conventional illuminants in this disc shape.

How did you develop the distinctive "sun rays" in the Discus design?

HG: We were looking for a powerful image on which to base the Discus design. We found this very powerful image of sun discs on pendants worn by shamans. These sun disc images are thousands of years old. In our eyes this archaic and very symbolic shape, in combination with modern high technology, is a perfect reflection of today's society in our eyes. As human beings we are influenced by stories, myths and rituals that have existed for thousands of years. But on the other hand, we are also very much influenced by modern technology, which we are not always able to understand fully. The combination of these differing aspects really represented the starting point of the design of Discus for us.

The rays fulfill an important technical function – is the design intended to explicitly underline this?

HG: The radial arrangement that you see in Discus calls to mind the symbolic shape of the shaman pendant. In addition, the radially-arranged blades are cooling fins that help to cool the LED module in the center of the spotlight. The design of the spotlight ensures that whatever position the spotlight is in, air is sucked in from below, cooling of the LEDs is guaranteed and the hot air is given off to the back. This is an excellent demonstration of our design concept – symbolic shapes should not only stand for themselves alone, but also be an integral part of a technical function. We don't consider design to be something that is added to a technical function. The shape that finally emerges is an interaction of a symbolic shape and technical necessity.

LINKS

Discus spotlight: www.zumtobel.com/discus

FIG. 3. EOOS design sketch for the Discus spotlight.

LED technology increases the importance of the illuminant's technical requirements: as a designer, do you also have to be a light technology expert now?

HG: Although we are talking about a spotlight here, the problem that had to be solved in this case was not based on light technology, but on heat technology. This also illustrates the changed approach to designing with LEDs. It's more a matter of how to get rid of the heat rather than a consideration of light technology aspects. The LED module is already optimized from a light technology point of view, and it really only needs to be cooled effectively. This means that instead of wrapping up and packaging, future designs will have to break open shapes to be able to meet the technical requirements of the LED. We hope that this strong archetypal shape of the spotlight will remain, only to be supplemented by ever more efficient LEDs.

Discus is especially suitable for sales and presentation applications – what do you consider to be the major advantages of the spotlight?

HG: Our experience as retail designers has shown that it is very important to have a structural design that can incorporate various different illuminants. So there shouldn't be any different sizes, only variations in light e.g. different angles of radiation, or different light sources. Our hope is that disc-shaped luminaires will predominate in the next few years. For retail applications, this should allow different illuminants to be used in combination with each other without having to fit different types of spotlights to the ceiling. ◀


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LED phosphor suppliers are affected by China's rare-earth export quotas

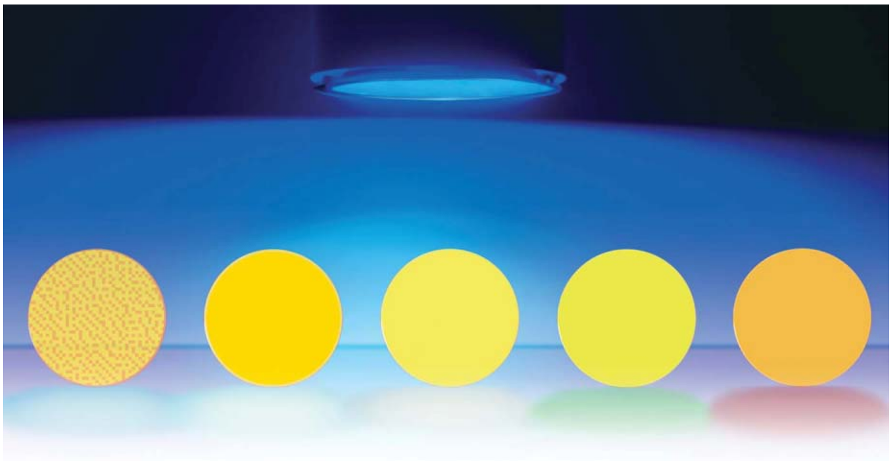
LED phosphors typically incorporate rare-earth elements, and manufacturers need to ensure that they have an adequate supply of these critical materials, as **TIM WHITAKER** reports.

The LED industry uses a wide and growing range of phosphor materials to convert the light emission from LED chips into a different wavelength spectrum. LED makers rely on their supply of phosphor materials as a crucial aspect of the production process. The most common use is the combination of a blue LED chip with one or more phosphors to create a white LED. Many of the phosphors used in LEDs contain rare-earth elements, and the availability of these materials is currently causing some concern, particularly because of new quotas introduced by China.

The 17 rare-earth elements comprise the lanthanide series in the periodic table (elements 57 through 71), plus scandium (Sc) and yttrium (Y). The most common LED phosphor is yttrium aluminum garnet (YAG) doped with cerium (Ce), another rare earth, while TAG phosphor contains terbium (Tb). Silicate phosphors such as BOSE and nitride phosphors are commonly doped with Ce or europium (Eu).

A key issue with rare earths is that China currently mines more than 95% of the global supply of these materials. For some of the elements, the so-called heavy rare earths, the figure is more like 99%. The materials have a wide variety of uses in many industries, and China is also a huge consumer. Crucially, however, China recently reduced its export quotas for rare-earth materials (http://nyti.ms/fEgS0Z). With the quotas being actively enforced, this will secure supplies for domestic Chinese manufacturers, and will also raise tax revenue for the Chinese government.

On the more positive side, China only has around 35% of global rare-earth deposits, and there are numerous efforts underway to exploit reserves in other countries. For example, US-based Molycorp Inc. (NYSE: MCP) plans to rapidly increase production at its mine in Mountain Pass, CA.



Intematix has introduced phosphor-coated plastic discs that act as both a remote phosphor and a diffuser optic (www.ledsmagazine.com/news/8/1/10).

However, this will take time, as Mike Pugh, worldwide director of operations for Intematix Corporation, a US-based phosphor supplier, explains. "In my view, China will have a stranglehold on the supply for about another two years," he says. "That's when other companies can come online with significant volume, predominantly in the USA and Australia. LED companies will have to manage this issue for the next 2 years."

The availability of different rare earths varies considerably from element to element, and their level of usage in LED phosphor depends on the material's chemical composition. For example, there's a relatively large yttrium content in YAG, while only a small amount of europium is used as an activator in certain red-emitting nitride phosphors. Material prices can be high, particularly for the heavy rare earths, and large price spikes can occur.

While pricing can be a concern, the availability of materials is critically important. "LED makers need to be sure their phosphor supplier has a secure supply of rare-earth materials," says Pugh. "The last thing an LED maker with big growth ambitions wants is to be placed on allocation by their phosphor supplier."

Some phosphor suppliers are thought to have large stockpiles of critical rare-earth materials. As for Intematix, Pugh explains that the company has two factories, one in California and one in China. In the USA the company makes nitrides and silicates that only require small amounts of rare-earth elements as activators, says Pugh, while the China factory is where the company manufactures its phosphor materials that have high rare-earth content. There is no quota for internal consumption in China. The government is also encouraging the export of finished goods containing rare-earth elements, driving value-added activities in China.

Another wrinkle is that Taiwan, which has a huge demand for phosphors, is also included in the quota for export from mainland China. This creates another incentive for Taiwan-based companies to build LED factories on the mainland.

standards | **UPDATE**

TM-21 seeks methods for lumen-maintenance prediction

Devising a standardized method to predict the long-term lumen maintenance of packaged LEDs and LED modules is not an easy task, writes **JIANZHONG JIAO** in his latest column on standards.

When lighting designers, specifiers, builders, and contractors evaluate or implement LED lighting products, just as with any other lighting technology, they want to know how long those LED lighting products will last. More specifically, they need to know how long it will take, in terms of hours or years, until the light output of these products is reduced to a level where they need to be replaced. Practically, the users want to know how to predict LED lighting lumen maintenance.

Without an existing industry standard, energy-savings programs in the US, such as Energy Star and the DesignLights Consortium (DLC), have established thresholds based on a simple mathematical model to make predictions, which are then used to qualify new products that are submitted for certification. The programs also have predetermined set periods of time (number of hours) over which test data for new products is collected. However, the duration of the test is relatively short in comparison to the manufacturers' claimed life of LEDs.

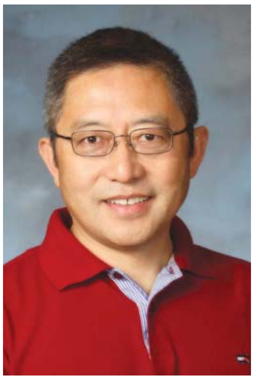
Although many industry experts disagree with the method currently in practice to qualify the wide variety of LED lighting products available, they also realize that energy-savings programs must have some rules to qualify these products.

TM-21 working group

After the IESNA Testing Procedure Committee (TPC) published in late 2008 its recommendations for LED lumen-maintenance testing methods, LM-80, a working group was formed within the TPC to address some unfinished business for LM-80. This concerned the method to predict LED lumen maintenance using the data obtained from LM-80 testing.

Recognizing the needs of LED users and the energy-savings programs, the experts in this working group have been working for over two years to develop a procedure which will be published as the document TM-21.

The reason this document has yet to be completed is due to the fact that developing a standardized method to predict LED lumen maintenance is not a simple task. There are a range of LED lumen-degradation mechanisms. Because LED technologies vary, when the LED products are tested over a short duration of time relative to their designed life, such as 6,000 hours specified in the LM-80 test, it appears that mathematical models derived from the data collected within this short time-frame can't be reliably used to make long-term lumen-maintenance predictions.



Scope of TM-21

Over the past two years, pressure has been mounting from LED users to develop lumen-maintenance prediction standards and there are high expectations and many misconceptions regarding the development of the TM-21 IESNA document. It may be necessary to clarify what the specific intent of TM-21 is and what the potential outcomes could be.

First, all of the published and developing standards for LED lighting are grouped into two levels; component level and system level. Similar to LM-80, TM-21 will be a component-level document that addresses lumen-maintenance predictions for packaged LEDs (or modules if they are tested per LM-80).

Second, as stated in the scope of the TM-21 proposal, this document "provides recommendations for projecting long-term lumen maintenance of LED packages using data obtained when testing them per IES LM-80." This sets the limit for what information is to be used for TM-21 i.e. the data from the LM-80 report. If an LM-80 report contains a minimum of 6,000 hours of testing data for an LED package under specific operational conditions of current and temperature, the 6,000 hours of data will be the basis for making a prediction.

Compared to the LED life claimed by the manufacturers (typically 50,000 hours), 6,000 hours is a rather small fraction. The lumen-maintenance test data from several LED manufacturers collected by the TM-21 working group clearly indicate large variations in LED behavior within the initial 6,000 hours. That variation is what leads to the significant challenge in developing a standardized method to generalize LED behaviors so that long-term lumen maintenance (e.g. L70 life) can be predicted with a unified formula.

JIANZHONG JIAO *(jianzhong.jiao@osram-os.com) is Director of Regulations and Emerging Technologies at OSRAM Opto Semiconductors, Inc. and is actively involved in LED and SSL standard development activities. He is Chairman of the SAE Lighting Committee, past Chairman of NGLIA, past Chairman of the NEMA SSL Technical Committee, active member of IESNA Testing Procedure Committee and Roadway Lighting Committee, ANSI SSL Working Groups, Standard Technical Panel member of UL8750, and member of several other organizations.*

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Engineering or statistical evaluation

Two approaches can be used to predict LED lumen maintenance using testing data. The first is an engineering approach. Initially this analyzes the causes of LED lumen degradation to identify if the light output loss over time is caused by aging of the LED chip, by material decay (encapsulation, lens, and phosphor), or by structural change (substrates, reflector, etc.). These degradations may be verified or distinguished by stress-testing LEDs under more severe conditions, such as high temperature, high humidity or high current. The experts can, based on their engineering expertise and the tests' findings, establish corresponding mathematical models. In turn, these mathematical models, once verified, can then be used to predict lumen maintenance.

The second approach is a statistical approach and is based purely on the testing data itself. For any given set of data, one or more mathematical equations can be applied to the data points, and then used to extrapolate the trends for making predictions. A set of rules and measures can be established to choose which mathematical model (or models) provides the best fit with the data. The model(s) can then be used to make extrapolations without any engineering judgments.

The engineering approach is largely based on experts' knowledge and understanding of the technologies and processes used in LED production, while the statistical approach is based on the rules and criteria that make the application of mathematical formulas reliable and consistent.

When LED manufacturers (or third-party researchers) produce LM-80 reports and relay their findings to the LED users (including LED luminaire manufacturers), the data only reflects the LEDs' behavior within the testing duration (e.g. 6,000 hours), and LED users are often unable to identify the causes for those behaviors. These behaviors make sense if the proper mathematical model(s) can be identified, which would not only offer the best fit for the data points within 6,000 hours, but also provide extrapolations that match the data points long beyond the initial testing period. Unfortunately, this is not the case. According to the industry experts, 6,000 hours of LED testing is too short to create accurate mathematical models that lead to reliable predictions.

LINKS

LED lighting community benefits from ongoing standardization efforts
LEDs Magazine February 2010, p59: www.ledsmagazine.com/features/7/4/7

Non-directional luminaires require new testing procedures for LED light engines
LEDs Magazine Nov/Dec 2010, p47: www.ledsmagazine.com/features/7/11/8

Dealing with a dilemma

Considering these facts, it appears that the industry is at a crossroads in regard to lumen-maintenance prediction. Mandating a longer testing duration, such as 10,000 hours or more, would certainly add more burdens to LED and LED-module manufacturers and delay the introduction of new technologies and products. However, setting up improper models or thresholds for using only 6,000 hours of LM-80 testing data could penalize good and long-lasting LED products. That is the challenge in establishing the TM-21 document. With such high expectations from the industry, the TM-21 working group continues to work on this challenging goal of recommending a practice that meets the need of lumen-maintenance predictions for LED users.

There are some alternative ideas being considered. One recommendation would be to establish the use or evaluation of 6,000 hours of LM-80 testing data as a provisional or conditional step towards lumen-maintenance prediction. The methods used to make predictions using 6,000 hours of LM-80 testing data should later be verified and validated with further testing over a longer duration. On the other hand, if the LED manufacturers possess the knowledge or know-how in predicting the long-term lumen maintenance of their products, their prediction models may be published together with the supporting LM-80 testing data. If the sets of rules and criteria can be established to qualify the correlation between the manufacturers' models and testing data, then it may be possible to validate predictions.

Predictions at the luminaire level

Establishing the TM-21 document will not fully resolve the additional challenge of lumen-maintenance prediction at the LED luminaire level. The TM-21 will be limited to the use of available LM-80 testing data, which is still on the component level. Although LED-package lumen depreciation is critical, the LED drivers and optical and thermal components used in the luminaires may affect the L70 life of the LED luminaires as well, but this will not be accounted for within TM-21. Therefore, IESNA TPC has established another working group focused on the development of lumen-maintenance testing standards at the system level, such as LED lamps, engines and luminaires.

outdoor lighting

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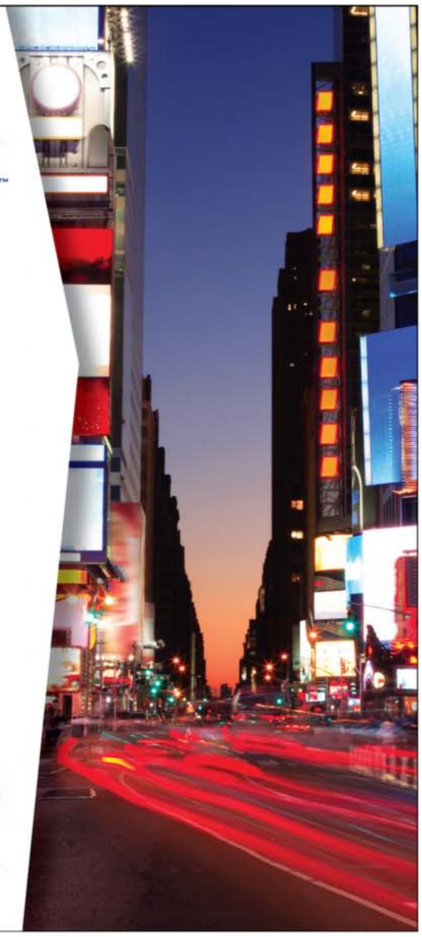
based on the energy savings, and induction installations are mainly earned back by the reduction in maintenance costs.

Plotting the lighting technologies in the spider web diagrams of Fig. 3 shows in one quick view the main differences in performance between various products or technologies. They allow for a visual communication of the performance parameters to expert and non-expert customers. I believe that such visual communication is an important tool to provide clarity and to help guide our customers through the complex and dynamic world of today's lighting systems.



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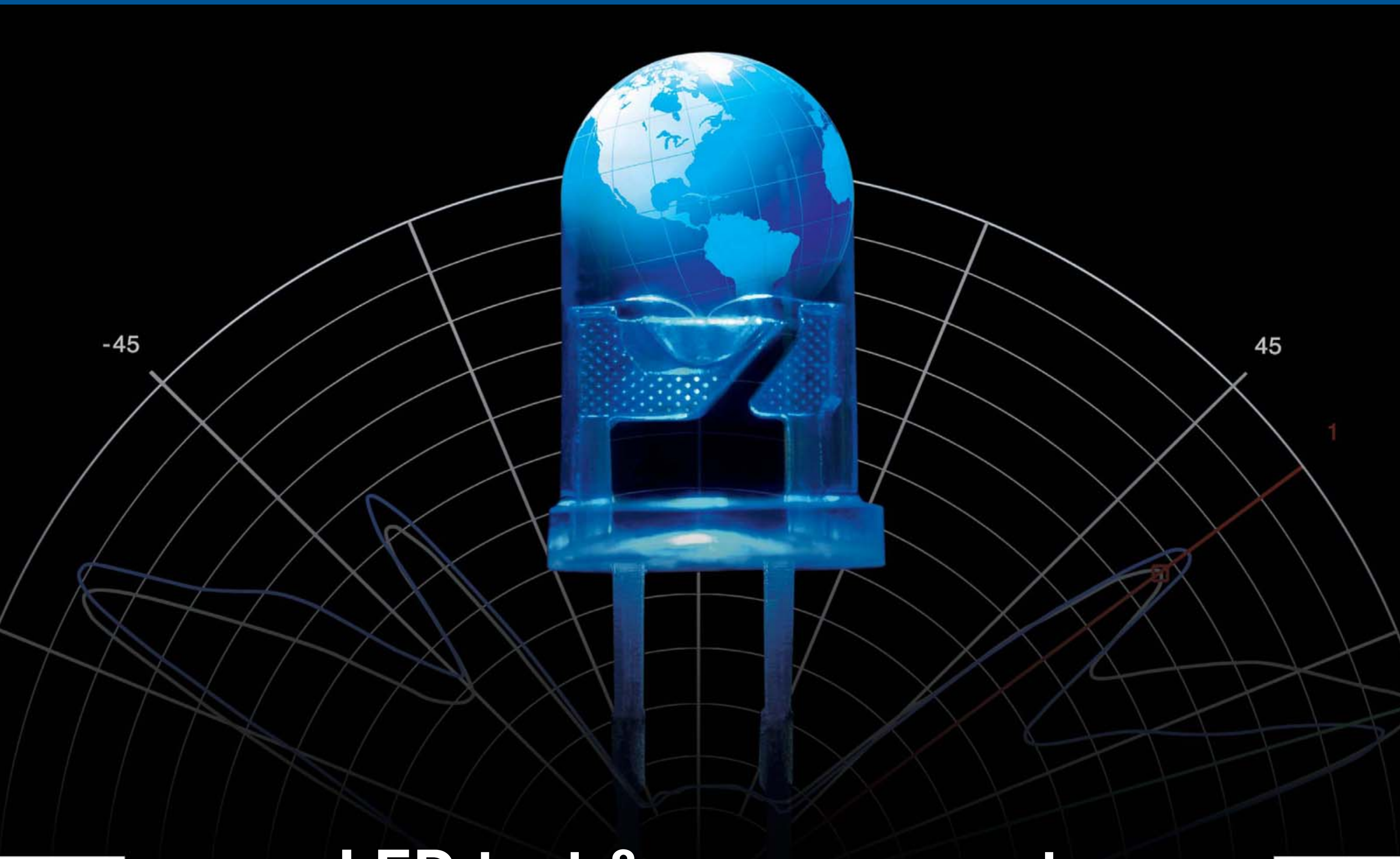

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Wireless networks enable city-wide control of LED street-light installations

Municipalities can add a wireless system to LED street-light deployments and implement remote power-monitoring and control functions including dimming, says **MAURY WRIGHT**.

Energy-efficient lighting technologies are quickly pervading street-light deployments globally as municipalities seek to save money and utilities try to forestall energy shortages due to generation shortfalls. LED-based street lights have perhaps the greatest potential for energy savings because solid-state-lighting (SSL) technology is more amenable to adaptive controls than are induction or ceramic-metal-halide options. Controls will allow dimming of lights for even greater savings during off-peak hours. Network and control systems, such as Roam from Acuity Brands Controls, enable remote control and monitoring of street lights utilizing a wireless mesh network.

Control networks, including the Roam Monitoring and Control system, aren't confined to SSL installations. Indeed Roam came to the market before SSL did and Acuity has supplied the technology with many types of legacy lights for power monitoring, on-off control, and detecting failed lamps. Dimming is an additive feature that's especially valuable with LED lights because the technology is amenable to dimming and delivering energy savings. For more information on different light sources, see the article from Philips Lighting on p 17.

Dimming can be used in a number of ways to cut energy usage. Our recent article on the Street and Area Lighting Conference (SALC) discussed an SSL installation in San Jose, California, where the roadway's classification changes from high capacity at rush hour to low capacity later at night (www.ledsmagazine.com/features/7/11/10). The city is dimming the lights as the traffic diminishes.

The city of Chula Vista, California has a trial site where lights follow a more complex operational pattern. According to consulting engineer Kenny Perez of Nate Mullen Visual Concepts, the BetaLED luminaires are first turned on at a dimmed level at dusk. As the night darkens, the programmatic control brings the lights to 100% illumination. At midnight the level is cut back to 50%. And then early in the morning the brightness is again increased as rush hour begins.

Dimming is very much an incremental feature on a network such as the Roam system. The monitoring aspect has led many cities to install the technology just to automate the street-light maintenance process. Cities can reduce maintenance cost via the ability to detect failed lamps thereby minimizing maintenance-truck outings.

Controls and dimming, however, are coming to the forefront with LED lighting. The city of Los Angeles, for instance, is installing Roam in what is the largest SSL street-light deployment in the US (see the SALC story for more information on the Los Angeles deployment). Los Angeles is not at present using dimming technology although they have indicated an intention to do so going forward. Terry Utterback, VP and Value Stream Leader at Acuity Brands Controls, reports that Los Angeles is testing dimming now. Utterback said, "I suspect if all goes well that they will move toward a dimmable fixture shortly."

FIG. 1. A cylindrical Roam network node module mounted on top of a street light.

The Roam network

Let's have a detailed look at how the Roam network operates because it is one of a few system-level approaches available to broad street-light deployments. Roam leverages a wireless mesh network to connect the individual street lights. A mesh implies that the gateway or base station device is not directly connected to each street light or node in the network. The node present in each luminaire can retransmit data that it receives, effectively increasing the reach of a base station.

The Roam system relies on the IEEE

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

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FIG. 2. A Roam wireless gateway links street lights via Ethernet or cellular backhaul.

802.15.4 specification as a basis for the physical and media-access-control layers of the network (for a refresher on network technologies for controls, see www.ledsmagazine.com/features/7/11/13). IEEE 802.15.4 is the same spec used in ZigBee networks, although ZigBee was really designed for shorter-range applications with node spacing in the 10m range. Roam has developed a network that can handle node spacing up to 1000 feet so long as there is a clear line of sight between the nodes, according to Utterback.

The mesh capability allows a single network to cover an area much larger than 1000 feet. The company has installed a single network that coves 8 linear miles of roadway. And in a deployment such as Los Angeles, the installation entails many networks that all connect to a single control center.

The Roam network uses the same license-free 2.4-GHz frequency band that is used by ZigBee. Moreover, both transmit data at 250 kbits/s. That is a relatively slow data rate compared to a high-speed Internet connection but fast enough to send control commands and receive status data from street lights.

Gateways and backhaul options

The base-station device that Roam calls a gateway (Fig. 2) connects to and controls a network of street lights. Roam has demonstrated as many as 2000 nodes on a network – that doesn't necessarily mean 2000 lights as you will learn shortly. The company believes that it might reach 5000 nodes per gateway. It's the gateways that link individual networks within a city-wide installation to the control center.

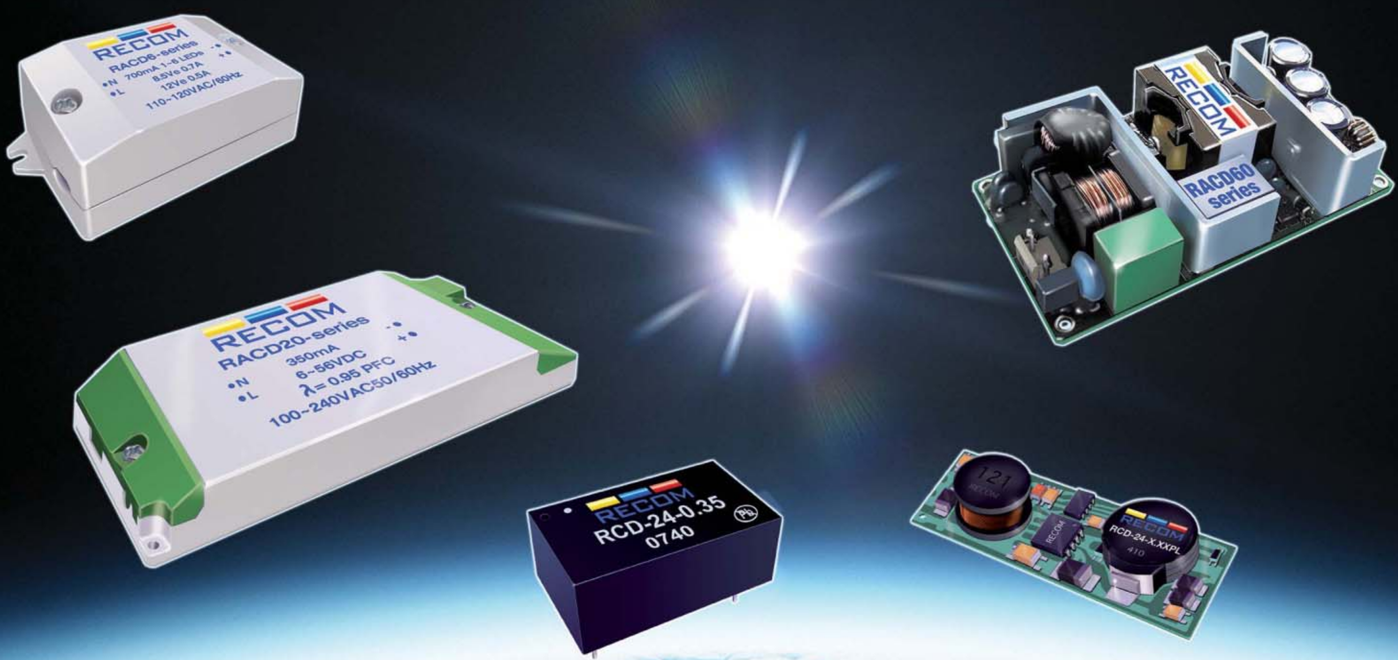
Roam added quite a lot in terms of network features to the 802.15.4 specification. Utterback said, "We added mesh, self-healing, and self-forming capabilities." Self-forming means that when a node powers up, it automatically seeks to communicate with other nodes and establish a link to a gateway. Self healing means that the network continues to operate when a node fails. Utterback said, "If you lose a node, no problem."

Installations of the Roam network can rely on either Ethernet or cellular-data connections for backhaul – connecting the street-light node to a control center. Utterback asserts than Ethernet works well in many relatively small networks.

Still, cellular is clearly the only choice in installations such as Los Angeles that are spread over large areas. Fortunately, the cellular system in most regions of the world carries data quite effectively these days. And the data load is again very small compared to say normal Internet usage. Utterback said the network typically takes 3-5 seconds between a command being issued in a control center to when it is received at a street-light node.

Luminaire installation

Having covered the basics of the network, let's discuss how the functionality gets added at the street-light luminaire level. Most street lights have a National Electrical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RACD6-series
RECOM
RACD60 series
RECOM
RACD20-series
350mA
6-56VDC
λ= 0.95 PFC
100~240VAC50/60Hz
RECOM
RCD-24-0.35
0740

Manufacturers Association (NEMA) connector on the top side of the luminaire. The NEMA connector is primarily provided so that photo detectors can be added to street lights to automatically turn on the lights at dusk and off in the morning. For the scheme to work, the power feed for the street light loops through the NEMA connector.

The Roam network nodes (Fig. 1) are implemented in modules that look similar to photodetector modules and that mate with the NEMA connector. Indeed the modules still include a photo detector, but also add the network node than can switch power on and off, and a monitoring circuit that can report the health of the street light and the energy being used.

The Roam system handles dimming separately. Acuity sells a Dimming Control Module (DCM) that must be integrated inside the luminaire to enable dimming. The DCM provides a 0-10V output that connects to standard 0-10V-dimmable drivers or ballasts.

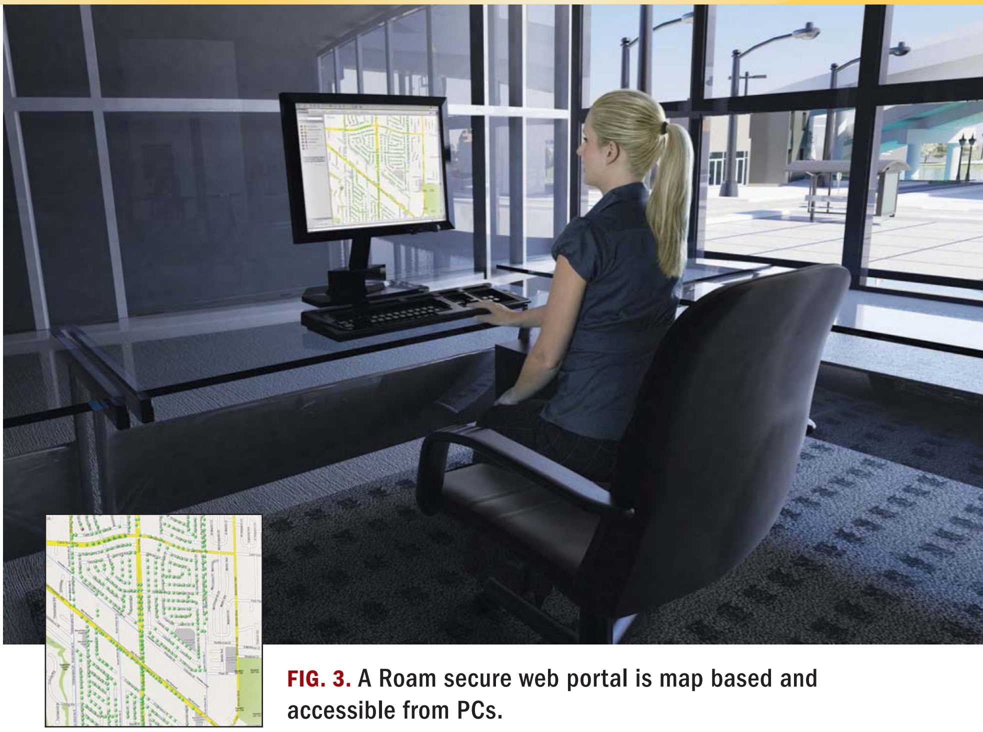

FIG. 3. A Roam secure web portal is map based and accessible from PCs.

The DCM is also a wireless network node. It takes its commands from the node in the NEMA-mounted module. But the DCM does count as another node on the wireless networks, and that's why a 2000-node network may not imply 2000 lights.

The Roam approach is both elegant in the simplicity of the concept, and also very different from how you might design a dimmable street light with a blank sheet of paper. The

NEMA interface means that monitoring and on-off controls can be added to almost any luminaire. Utterback asserts that the process takes 3-5 minutes. And many luminaire designs will be able to accommodate DCMs, although those may be custom purchases specified to a luminaire maker.

With a blank sheet of paper, you would certainly integrate the on-off control, dimming control, and monitoring functions directly into the driver electronics and rely on a single network node. A simple microcontroller could both handle the network functionality and even execute LED dimming algorithms and control the driver electronics. But that integrated approach would essentially require that we have either a *de facto* or formal industry standard for street-light networks so that all manufacturers could build interoperable products.

When asked about network standards, Utterback indicated that the company is tracking initiatives such as 6LoWPAN (IPv6 over low power wireless area networks). The technology is meant as a way to connect devices to the Internet and is also referred to sometimes as supporting machine-to-machine networks – as opposed to people using PCs. Utterback said, "If any standards develop traction, we can update nodes via over-the-air programming." Basically the network protocols in the nodes could be updated remotely.

Network control center

The final piece of the Roam system is the network control-center capability that consolidates monitoring and control operations. The Roam system can deliver a control console via a secure web portal that city personnel can access on their desktop PC. An IT system that supports monitoring and control functions and even maintenance work-order management underlies the portal. The network services are an integral part of the Roam system, and indeed add to the cost of an installation.

The web portal is based on the deCarta maps engine that underlies Google Maps. Municipal personnel can view each street light on a map and easily access monitoring and control functions.

Alternatively, the Roam data can also be fed into existing IT systems. For example, Los Angeles already had an extensive map-based IT system in place to monitor, control, and schedule street-light operations. Acuity is able to feed data from its street-light network control center into the Los Angeles IT system in a XML format.

Controls will compound the energy-saving potential of SSL and in the case of street lights reduce maintenance costs by automatically detecting failed lights.

Future articles will continue to examine options for adaptive controls in general- and street-lighting applications. We will look at other wireless network options and alternative network technologies such as power-line communications.


Asking some little piggy to do
laundry when you go to market,
not very efficient.

LightSavers LED street-lighting pilot project yields encouraging results

A pilot SSL street-light project in Caledon, Canada tested LED luminaires from three manufacturers. **MAURY WRIGHT** describes the generally positive results for illuminance, uniformity, and lumen-depreciation after a full year since deployment.

The LightSavers project of the Toronto Atmospheric Fund (TAF) has collected a year of data related to a pilot installation of LED-based street lights in the town of Caledon, Canada. The LightSavers group has measured the optical performance of the solid-state lighting (SSL) installation and existing metal-halide (MH) lights on a biweekly basis. The pilot has documented an advantage for the LED lights in terms of illuminance, energy savings, uniformity, and lumen depreciation, but the greater cost of the SSL luminaires yielded a relatively lengthy projected payback of 14 to 18 years. Still, the falling price of LED lighting and the increasing efficiency of luminaires will continue to drive down the payback period.

The Toronto Atmospheric Fund (TAF) created the LightSavers (www.lightsavers.ca) project to accelerate the use of advanced lighting and adaptive controls to reduce both energy usage and greenhouse gas emissions. Subsequently, The Climate Group licensed the LightSavers trademark from TAF and established a LightSavers program (www.theclimategroup.org/programs/lightsavers) to purse LED-lighting and smart-controls projects globally. Three of the TAF pilot projects, including Caledon, are part of the global Climate Group program. The global program allows The Climate Group to compare results from pilots around the world and distribute results globally as well.

Caledon municipal site

The Caledon project is located in a parking lot adjacent to a municipal building. The town handled procurement of the LED lights and the TAF LightSavers program handled the data gathering and tests over the course of November 2009 to November 2010. The project was relatively small in scale, involving only nine LED lights. But LightSavers was able to evaluate LED luminaires from three manufacturers and deliver accurate and actionable results.

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

FIG. 1. One of the Elumen LED street lights with a illuminance measurement location marked in red on the pavement.

TAF and Caledon chose the pilot site in part because the existing MH lights were performing poorly. Specifically, the lights were experiencing excessive lumen depreciation leading to annual replacement of the MH lamps. LightSavers conducted the pilot using the LightSavers Monitoring and Evaluation Protocol that is available on its website.

Caledon asked SSL manufactures Elumen, Relume, and Ruud (BetaLED) to provide LED luminaires that were "substantially equivalent" in terms of optical performance to the existing 175W Philips Gardco CR20 4XL MH lights with a Type IV beam pattern (for more information about beam patterns, see www.ledsmagazine.com/features/7/9/8).

The town installed three luminaires from each vendor in different areas of the parking lot. Fig. 1 shows one of the installed Elumen luminaires. Fig. 2 shows the data collection sheet that LightSavers used to record optical performance. The luminaires were installed at a height of 5m.

In each of the four test areas, LightSavers defined a grid in which it would take eight illuminance measurements. The team marked a spot on the pavement in each of eight rectangles for each of the four test areas. They consistently made illuminance measurements using the exact same marked spots.

The pole spacing was not constant, but the tests in each area were located around two of the luminaires as marked by the letter x in Fig. 2. Despite the slightly irregular layout, LightSavers sought in each case to take measurements directly in front of luminaires and between luminaire pairs.

Illuminance measurement methodology

Prior to beginning the measurement process, the team installed new lamps in the baseline MH fixtures. The team operated the new lamps for 100 hours to ensure that the lamps would achieve full output. Likewise the team operated the LED lights for approximately 100 hours before taking any measurements.

To kick off the test, the team took power-consumption and illuminance measurements on November 10, 2009. Subsequently the team repeated the illuminance measurements twice per month. The team made the measurements at least an hour after sunset using a Cooke cal-LIGHT 400 light meter. The team also recorded the temperature and atmospheric conditions at measurement time.

Fig. 3 summarizes the results of the tests. The bar chart shows the average and minimum illuminance measurements (in lux) for the MH and LED lights. As you can clearly see, two of the LED fixtures significantly outperformed the MH lights.

The chart also includes a line that represents the Illuminating Engineering Society (IES) recommended minimum value for an Enhanced Security lot.

Lumen depreciation

The LightSavers team also wanted to study lumen depreciation and that's one reason the test ran for a full year. Possible lumen depreciation issues remain an obstacle to broad adoption of LEDs in outdoor applications. To be economically viable, LED lights must deliver more than 70% of their original light output (L70) over long life spans. The luminaires tested in Caledon were all rated for 100,000 hours, equating to about 22 years in the parking-lot application.

Based on a 100,000-hour life estimate, the luminaires would have to maintain annual depreciation under 2%. The MH lights depreciated 51% over 12 months. TAF LightSavers Program Manager Bryan Purcell noted that the depreciation was unusually high for an MH lamp. Diagnosing the reason for the excessive MH depreciation wasn't part of the pilot's objective, but Purcell theorized that perhaps the gaskets in the MH fixtures weren't sealing properly and moisture was impacting performance.

The Elumen luminaires are designed to gradually increase drive current over time to combat depreciation. The measurements over the course of the year were sporadically above and below the first measurements taken with the final measurement being 11.5% higher than the first. LightSavers believes that the products are on track to deliver more than 20 years of life.

The Relume luminaires did generate

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some measurements throughout the year that were lower than the first taken. But the last measurement made was exactly the same as the first. The LightSaver team believes that leaves on nearby trees blocked some of the light and impacted the measured performance during a portion of the year. And the team believes the data does indicate a lifespan of greater than 20 years for the Relume products.

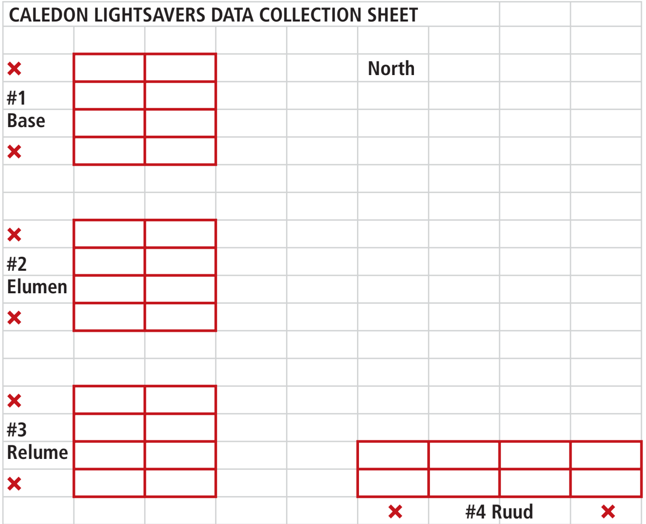


FIG. 2. The data collection sheet shows roughly the eight areas on a grid where LightSavers took illuminance measurements relative to the light poles marked as red x's.

The Ruud luminaires suffered depreciation of 8.9% over the course of 12 months. The LightSavers team believes that part of the problem was premature failure of an adjacent MH luminaire that spilled light into the Ruud SSL test area. The team replaced the MH lamp at the end of the test and that improved the depreciation figure but still didn't bring it to the 2% target. The team is planning additional photometry tests on the Ruud luminaires.

Using the temperature measurements taken with each illuminance measurement, the LightSavers team also sought to correlate optical performance with temperature since thermal design is an important consideration in SSL. The results showed only a slight correlation between high temperature and low light levels, leading the team to conclude that all of the test luminaires had robust thermal designs.

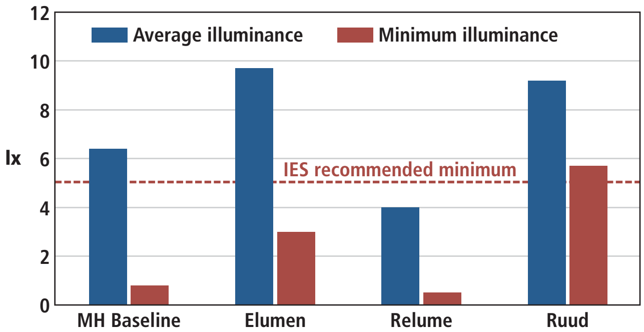


FIG. 3. A chart of average and minimum illuminance (lx) measurements after 12 months for the four test cases, along with the IES recommended minimum value.

Power measurements and savings

LightSavers measured the current used by each of the luminaires and then calculated the power consumption. The MH lights use 218W. The SSL power measurements were a bit more complicated. The existing MH lights were powered by a 347V input. At the time of the procurement, none of the SSL vendors had luminaires that would operate from that high voltage. The town installed a transformer at each of the SSL poles to deliver 120V to the LED luminaires. The LightSavers team made the current measurements after the transformer so that power loss in the transformer was not included in the comparative data.

The SSL luminaires use 92W, 70W, and 67W for the Rudd, Relume, and Elumen products respectively. Power consumption will increase slightly over time in the Elumen case because the design gradu-

Economic Performance for Early Replacement Scenario

Fixture	Cost	Annual Energy Savings*	Avg. Annual Maintenance Savings	Simple Payback**	20 Year Return on Investment**
Elumen	$1,349	$50	$36	14.2 Years	47%
Relume	$1,772	$49	$36	17.3 Years	18%
Ruud	$1,651	$41	$36	17.9 Years	15%

* At $0.075/kWh
** Assuming 3.5% annual inflation in energy prices

FIG. 4. Payback varies from 14 to 18 years in the Caledon project although SSL prices have dropped considerably since those fixtures were procured and that would shorten the payback considerably in current analysis.

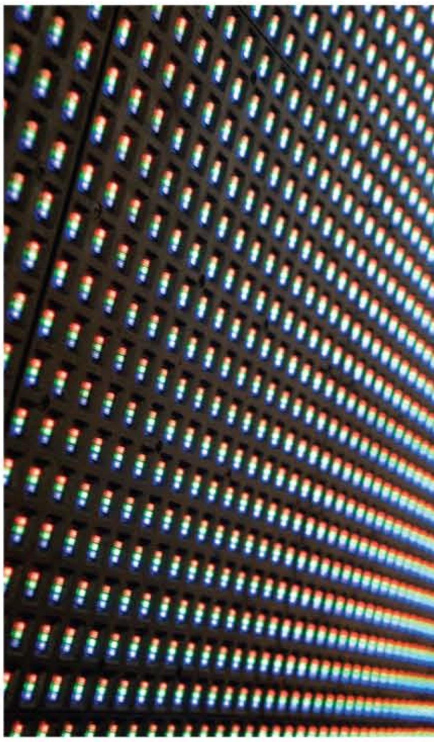
ally ramps up the drive current to counter lumen depreciation.

Fig. 4 summarizes the cost of the products, the savings, and the calculated simple payback period for an SSL retrofit. The costs include the price of the transformer in the case of the SSL luminaires. While the payback ranges to almost 18 years, the investment could still be a good one if the lights deliver more than 20-year lifespans. The LightSaver team also considered a case where LED lights were installed rather than MH lights in new-construction or end-of-life scenarios. That shaved three years from the payback periods.

In reality, the payback periods would look even better were the project done today given the drop in SSL prices since Caledon bought their lights, new SSL luminaire features, and higher-volume purchases. Purcell said, "One thing that drove up costs in this project was that we had to install transformers to make it work with 347V. Next-generation products are now available for 347V which really improves the economic picture."

The Climate Group's Cities and Technology Director Philip Jessup pointed out that the relatively high price of the LED luminaires was related to the fact that it was a very small purchase. Jessup said, "Higher volume purchases in larger cities will bring the price down. For example, consider Los Angeles where they've gotten the price for street-light LED luminaires down to around $400 each."

The LightSavers team concluded that a luminaire price below $1000 would yield payback inside 10 years. That's certainly a reasonable expectation for prices in 2011.



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High LED drive currents with low stack voltages create efficiency challenges

The SSL industry is beginning to do a better job of optimizing the LED components, drive electronics, thermal design, and optical elements of a luminaire according to **MATTHEW REYNOLDS**, who details the energy-efficiency challenge.

In the relatively short life of the LED-based solid-state lighting (SSL) industry, there has been a lot of buzz about a system-level solution or design. This conceptual solution requires an optimization of disparate disciplines or technologies including LED components, thermal design elements, optics, and driver electronics. Only recently has the multidisciplinary systems approach begun to take hold as experts in each area deliver optimized subsystems. But obstacles remain. For example, brighter LEDs that can be driven at higher current levels create power efficiency challenges in the driver electronics. Driver designs and LED enhancements must evolve together to deliver efficient luminaires.

Over the last ten years LED manufacturers have increased the efficacy of LEDs at a rapid pace. SSL solutions were not as cost effective as existing technologies and LED manufacturers were focused on lumens per watt, or even better, lumens per dollar.

Power electronics and IC manufacturers have had more than 30 years of experience with AC/DC and DC/DC voltage regulation topologies to draw from in considering the LED drive problem. Although SSL requires a constant-current driver that's different from the more typical voltage-regulation applications, the technical knowledge and power electronics manufacturing expertise were already in place. LED driver topologies found in initial SSL products were largely modifications of existing voltage-regulation schemes. Efficient AC/DC LED drivers, however, have unique requirements. These requirements have re-energized the power-electronics community to develop efficient, reliable and cost-effective solutions targeted at the SSL driver market.

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SSL systems cost shapes designs

In order for SSL luminaires to attain mass adoption, the end solutions must be cost-competitive compared to incumbent light sources. LEDs are the most expensive component of an SSL luminaire bill of materials (BOM). LEDs have been manufactured on relatively small wafers, and the manufacturing hasn't been fully cost-optimized. That situation is improving. But luminaire manufacturers realized that the easiest means to reduce system cost was to reduce the number of LEDs in the system. The SSL industry has pushed the LED manufacturers to create LEDs with greater efficacy numbers, as well as LEDs that had increased lumen output – higher power LEDs that operate at higher drive currents.

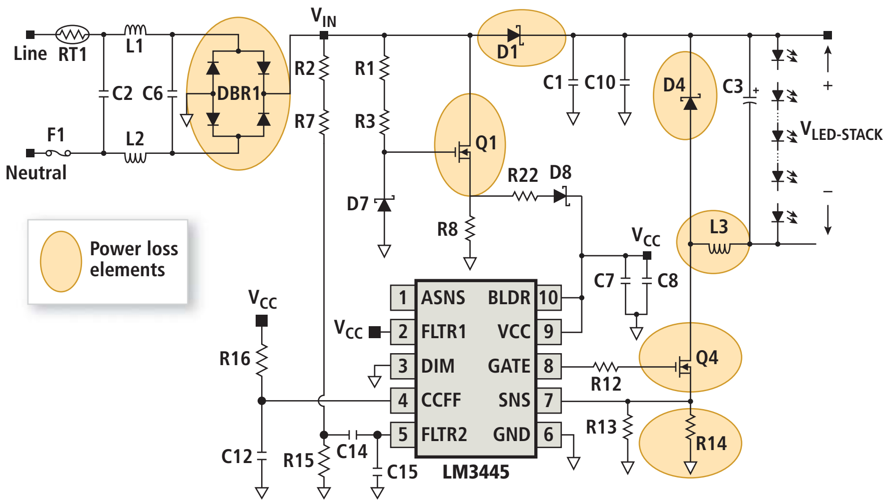

FIG. 1. Typical retrofit LED lamp circuit used in the optimization experiments.

With technology maturation and programs like Energy Star and the US Department of Energy's Lighting Facts Label, all of the pieces have been put in place to push SSL to mass adoption. The LED manufacturers have made amazing progress with the efficacy of the LEDs. The optics industry has minimized the lumen losses and increased the quality of their optics. The power electronics and IC manufacturers have developed drivers and optimized for LEDs. All was good, or so we thought...

A looming issue became apparent, however, as luminaire manufacturers adopted

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higher-power LEDs and steadily decreased the number of LEDs needed in a system. Fewer LEDs was good for product costs, but it created an unforeseen technical challenge in energy efficiency for the industry. The problem was first noticed in the A19/E27 lamp retrofit market.

The SSL industry assumed that the LED driver would increase in efficiency (or at least remain similar to past designs) as the number of LEDs were reduced in the system and as the LEDs increased in lumen output. It turns out efficiency dropped. Let's look at an example, and then discuss what went wrong.

Typical SSL retrofit bulb specification

A typical SSL replacement lamp for a 60W incandescent bulb met the following specifications:

- Voltage – 10 LEDs in series (31V – 36V)
- Lumen output ~ 800 lumens
- LED forward current – 350mA
- Output power (max) – 12.6W
- Efficiency target – 85%
- Input power ~ 14.82W
- System efficacy ~ 53.7 lm/W
- Internal power dissipation ~ 2.3W

With brighter LEDs available, the SSL industry expected to reduce the number of LEDs in the system, increase the LED drive current, and make a slight gain in efficiency. A target for the next generation retrofit lamp included the following specifications:

- Voltage – 5 LEDs in series (15V – 17V)
- LED forward current – 700mA
- Lumen output ~ 800 lumens
- Output power (max) – 11.9W
- Input power ~ 14W
- Efficiency target – 85%
- System efficacy ~ 67 lm/W
- Internal power dissipation ~ 2.1W

The reality was that the design with fewer LEDs didn't meet the specifications. The designs did hit the lumen output goals and the output-power specification. But the design didn't meet the efficiency target and the system efficacy dropped. The design delivered these specifications:

- Voltage – 5 LEDs in series (15V – 17V)
- LED forward current – 700mA
- Lumen output ~ 800 lumens
- Output power (max) – 11.9W
- Input power ~ 15.9W
- Efficiency target – 75%
- System efficacy ~ 50 lm/W
- Internal power dissipation ~ 4W

System efficacy was certainly a problem and Energy Star compliance could be in question with the realized design. Power dissipation was also alarming for other reasons. The heat from the power loss could cause reliability issues. The heat issue could also increase cost due to more elaborate heat sinks or the need for potting material around the electronics.

Understanding power losses

To understand the cause of the drop in efficiency, let's review sources for power loss.

Losses within the power conversion stage can be categorized into three types, namely conduction losses, switching losses and quiescent losses.

All silicon devices and passive components within an LED driver have resistance associated with them. Conduction of current through resistances results in $I_{RMS}^2 \times R$ power losses. Depending on the quality and type of components chosen (MOSFET, diode, magnetics), losses could vary as the system specification varies.

Switching losses occur during the transition from one MOSFET or diode being turned on while the other MOSFET or diode is being turned off. A converter operating at 200 kHz will have twice as much switching loss relative to a converter operating at 100 kHz, but there is a trade-off between operating switching frequency and power loss that must be evaluated. Switching at higher frequencies allows for lower inductance values and smaller components allowing for larger wires that can reduce conduction losses.

The quiescent power losses are associated with powering internal circuitry. In similar LED driver designs, you may have the same output power ($P_{OUT} = I_{LED} \times V_{LED\text{-}Stack}$) but depending on the voltage, and currents of the system, and the type of components within the system efficiency of the system may vary wildly.

Looking at the circuit in Fig. 1, and considering the sources of power loss, one could quickly make some assumptions regarding stack voltages (the voltage drop across a stack of series-connected LEDs) and currents (the current through the stack) in an SSL lighting application. By increasing the current through a reduced number of LEDs, the lumen output may meet specification, but efficiency will likely decrease. A quick analysis identifies the following operational characteristics that lead to the efficiency drop in the system:

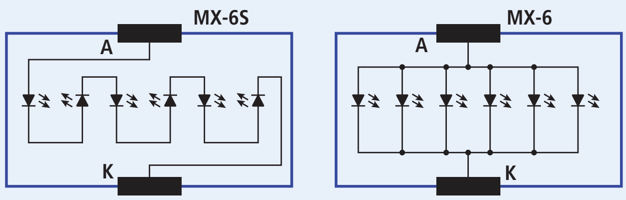

FIG. 2. Cree MX-6 and MX-6S LEDs.

The conduction losses in the inductor L3 will increase as the LED forward current increases.

Switching losses in the free-wheeling diode D4 increase if the LED forward current is increased.

By decreasing the stack voltage you have increased the percentage of time the free-wheeling diode D4 is conducting relative to the time that the main switching MOSFET Q4 is on. This diode will have larger conduction losses than the MOSFET, and therefore power loss in the system has increased.

Conduction losses will increase in the main switching MOSFET Q4 with increased LED current.

System-level approach delivers efficiency

The good news is that a system-level approach can deliver more efficient SSL products including retrofit lamps. Optimization from the chosen LED components through the driver can deliver a cost-effective product that also meets efficiency and reliability goals.

The power electronics community has taken on the challenge of developing LED driver solutions that are efficient even in cases where the LED stack voltage is very small relative to the input voltage. Moreover, National Semiconductor and others have created LED drive electronics that allow luminaire manufacturers to achieve Energy Star compliance.

After analyzing many different types of LED and driver configurations in the laboratory, it became apparent that the lower LED count with higher forward current would present an increased challenge to achieve Energy Star compliance for lamp makers. Concurrently, the LED manufacturers recognized that focusing on developing efficient single LEDs is not the whole story. LED manufacturers are increasingly aware of how their LEDs are being used in the market, and are configuring their LEDs to help optimize a specific SSL solution. LEDs used in retrofit A19/PAR type lamps must be very different than street-light and MR16 applications. By working with design teams from other areas of expertise the LED manufacturers have recently released LEDs specific to the end application.

LED manufacturers have begun to offer application-specific LED products. One such product from Cree is the new MX-6S. The MX-6S LED is reconfigured from the older MX-6 LED, but this particular LED offers significant benefits if used in the right application, and in this case its benefits are recognized in retrofit

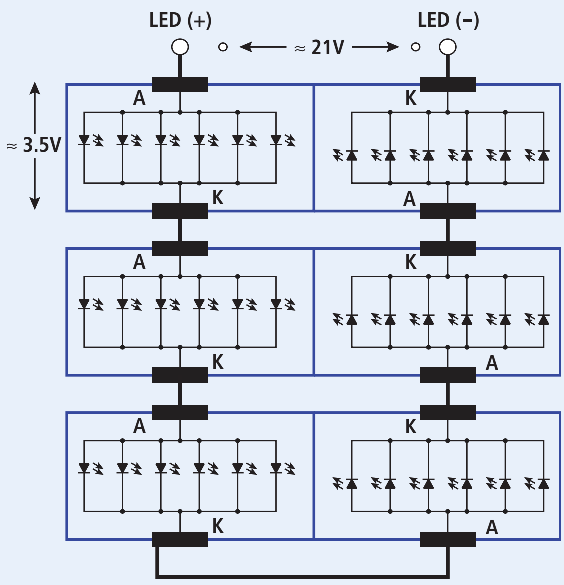

FIG. 3. Cree MX-6 LEDs configured in series to implement an 800-lm lamp.

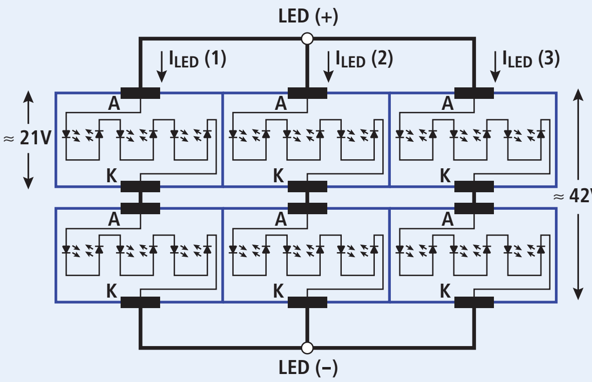

FIG. 4. Cree MX-6S LEDs configured in a 3 x 2 array for an 800-lm lamp.

lamp applications. The original MX-6 LED has six LEDs in parallel within a single package. Each LED within the package would handle up to 150mA, for a total LED current of up to 1000mA. The LEDs have a forward voltage between 3.2V and 3.6V.

The new MX-6S LED has the six internal LEDs configured in series. The forward current of the series string is up to 115mA. The single MX-6S package LED has a forward voltage between 19V and 22V. Simplified LED configurations within the packages are shown in Fig. 2.

The LED dice in both the MX-6 and MX-6S are identical – assuming the dice came from the same binning selection. The only difference between the two LEDs would be their internal bonding configuration. This single variable allowed for an excellent bench analysis between LED stack voltages in an A19 SSL lamp application with a common LED driver.

MX-6 vs. MX-6S bench analysis

We performed a bench analysis to consider how a retrofit lamp might utilize the Cree LEDs and the operational characteristics of each. The analysis between LED stack voltages and currents had the following goals and criteria:

- Optimize a common LED driver for SSL retrofit lamp applications with different LED configurations
- Record power loss and record critical component temperature
- Record any significant cost benefits with one design compared to the other
- Formulate driver and LED configuration recommendations with performance, cost reliability and manufacturability metrics in mind.

We adjusted LED currents to obtain a specific light output between the two designs. With equal lumen output we had fairly comparable system variables such as lumen loss due to temperature. We carefully controlled variables such as light-measuring equipment, heat sinks, and mechanical design to deliver comparable results.

We performed an empirical analysis on the low- and high-voltage stacks in a prototype design. The SSL lamp design was equivalent to a 60W incandescent bulb with the following design criteria:

- V_{IN} 115VAC (+/-20%)
- PF > 0.70
- SSL bulb lifetime > 30k-hours
- Reverse & forward phase dimmer compatible
- Dimming ratio > 50:1
- 60W incandescent equivalent (~ 800 lm)

A simplified schematic of the design (Fig. 3) comprises six MX-6 LEDs connected in series driven at 600mA. Each LED delivers approximately 133 lm/W at 600mA. Table 1 summarizes the operational characteristics.

A simplified schematic of the MX-6S-based design is shown in Fig. 4. The design utilizes six LEDs that are configured in a 3 × 2 array. The total output current is 270mA, with each string driven at 90mA. Each LED delivers approximately 133 lm/W at 90mA. Table 2 summarizes the operational characteristics.

Thermals analysis and reliability

To perform a thermal and reliability analysis, we placed the LED driver in a plastic

Table 1. MX-6-based lamp operational characteristics.

# LEDs	I_{LED} (mA)	V_F LED	V_O	P_O (W)	Eff (%)	Power Dissipation (W)
6	600mA	3.65	22	13.2	78.00	3.72

Table 2. MX-6S-based lamp operational characteristics

# LEDs	I_{LED} (mA)	V_F LED	V_O	P_O (W)	Eff (%)	Power Dissipation (W)
6	90mA X 3	21.25	42.5	11.5	86	1.75

Table 3. MX-6 data.

Input Voltage	LED stack Voltage	LED current	Efficiency
115VAC	21.6	600mA	78%
Thermocouple #	**External Element**	**Temperature 20min**	
1	Electrolytic Capacitor	65°C	
2	Main MOSFET	100°C	
3	Inductor	101°C	
4	Output Diode	120°C	

housing and inserted it into a common PAR38 aluminum fixture. The driver and LEDs were assembled typical to a PAR38 retrofit bulb solution. The design was first configured for six-series connected MX-6 LEDs at 600mA. We attached thermocouples to the electrolytic capacitor, main switching FET, main rectifier diode, and output inductor. A bench test delivered the data in Table 3.

We repeated the test using six MX-6S LEDs in the configuration from Fig 4. Our tests delivered the data in Table 4.

Table 4. MX-6S data.

Input Voltage	LED stack Voltage	LED current	Efficiency
115VAC	40.15V	300mA	86%
Thermocouple #	**External Element**	**Temperature 30min**	
1	Electrolytic Capacitor	51°C	
2	Main MosFET	80°C	
3	Inductor	98°C	
4	Output Diode	90°C	

Conclusions

System design engineers should conclude from this simple analysis that the areas of most concern are the temperature differences of the critical components within the LED driver electronics between the two designs. There is little direct cost implication between the two designs. But the temperature difference could be catastrophic to the manufacturer due to returns, and a reputation for poor quality. Cost could be an indirect consequence if the manufacturer was determined to use a particular LED configuration and then was required to increase the efficiency with expensive drive electronics components, or was required to add additional heat-sink or potting material to ensure the system components were within proper thermal specifications.

Often the electrolytic capacitor is the determining factor in the life expectancy of the drive electronics. If proper attention to design is taken, electrolytic capacitors can be used with confidence to gain >50k hours of life in SSL applications. A rule of thumb is that for every ten degrees Celsius you increase the temperature of an electrolytic capacitor, you half its life. For example, if you were to use a 105°C 10k-hour rated electrolytic capacitor and operated it at 85°C, the capacitor would be considered good up to 40k hours. If the same capacitor was operated at 95°C, the life expectancy would be about 20k-hours – a big difference. In our test case, operational life would at least double with the use of the higher-voltage stack LEDs.

Mergers and acquisitions will remain a regular feature of the energy-efficient lighting market

The energy-efficient lighting category has experienced a substantial amount of strategic acquisition activity for the past several years, and this trend should continue, according to **TRISHA HANSEN** and **DAVID CUMBERLAND**.

Top lighting companies are leading the transition of the lighting sector toward energy-efficient lighting (EEL). The market opportunity for energy-efficient lighting is large: the US Department of Energy has estimated the annual sales for the global lighting market at more than $80 billion, with energy-efficient lighting representing only a small percentage of the total. The segment of EEL with the most potential appears to be solid-state lighting (SSL) provided by LEDs, which can result in superior energy efficiency relative to traditional alternatives.

Adapted from the Energy-efficient Lighting report published in late 2010 by Robert W. Baird & Co., this article summarizes the actions and plans designed to enable leading lighting manufacturers to capitalize on the significant growth prospects of energy-efficient lighting.

Primary growth drivers

Energy-efficient lighting should experience rapid growth for an extended period, thereby drawing the focus of key lighting companies. The primary growth drivers of the EEL market include:

Expanding applications: Many commercial applications for SSL have become practical only in recent years as quality has improved and production costs have declined. Based on the latest technology developments, SSL holds important advantages over legacy lighting in terms of energy efficiency, longevity, maintenance costs, directional light output, variety, versatility, non-toxic composition, heat radiation, durability, and compact size.

Greater interest in energy efficiency: The combination of high energy prices and increasing environmental awareness has strengthened the focus on energy efficiency. Among efforts to reduce energy costs and consumption, lighting efficiency stands out as having the largest possible impact.

Technology advancement: As output and efficiency increase, declines in manufacturing costs and end-user prices support large-scale adoption.

Government regulation and incentives: Based on the environmental and monetary impact of energy policies, government bodies globally are taking additional steps to promote energy efficiency, including implementation of regulations and subsidies tied to renewable energy production.

Economic cycle upturn: Following the recent global economic downturn, improved trends for industrial activity provide a backdrop for growth.

Developing markets: Emerging markets represent a growing source of demand for EEL through industrial expansion, population growth, and increases in per-person usage of electricity.

Strategic acquisition activity

The EEL category has experienced a substantial amount of strategic acquisition activity for the past several years, and this trend should continue. Acquisitions have been driven by attractive growth prospects, high barriers to entry, economies of scale and scope, and the benefits of a broad geographic presence in a global market. Past acquisitions by leading lighting companies illustrate the importance of key success factors for participants in the EEL sector, including innovation, intellectual property (IP), proven R&D processes, brand name recognition, and distribution networks. Buyers have demonstrated the willingness to pay premium multiples for technology-based acquisitions.

The fragmented nature of the lighting products sector results in significant consolidation opportunities. In addition to stimulating interest among end users, the broad-based push toward energy efficiency has enhanced the appeal of EEL companies to larger acquirors. Distribution partners and end users are relying heavily on leading lighting products manufacturers in the transition toward EEL, motivating companies to expand their EEL capabilities, often via acquisition.

Recent activity

Recent acquisition activity and management commentary underscore the high level of interest in EEL among leading lighting companies. Here are some examples:

Philips, a global leader in lighting products, projects LED lighting to capture about half of the general illumination market by 2015. This compares to LED lighting representing a single-digit percentage of recent

TRISHA HANSEN *is a Director, Investment Banking and* DAVID CUMBERLAND *is Director, Mergers & Acquisitions Research with Robert W. Baird & Co. (www.rwbaird.com).*

lighting sales for Philips. The company has indicated its focus on growing its owned IP portfolio. In 2008, Philips purchased Genlyte, the number two lighting fixture company in the US, providing increased access to US distributors for its LED business. The Genlyte transaction was preceded by a series of sizable LED lighting deals in 2006 and 2007.

As a lighting market powerhouse, **GE Lighting** is likely to invest heavily in building its EEL business via organic growth while also evaluating acquisitions. GE has expressed its intention to compete on technology, suggesting an interest in IP as a sustainable foundation for lighting products that deliver superior efficiency and quality. The focus on LED-related R&D ties with GE's lighting strategy of offering the best quality in LED technology.

Global lighting leader **Acuity** has made considerable progress on growing its EEL business. The Sensor Switch deal of 2009 secured market leadership in occupancy sensor products and technology for lighting controls. The 2010 acquisition of Renaissance Lighting brought a highly valuable IP portfolio related to advanced LED optical solutions and technologies.

Cree, a leading supplier of LED components, acquired LED Lighting Fixtures in 2008 to strengthen its position within the sizable market for LED downlights, a large segment of indoor lighting.

Cooper Industries has shown its commitment to EEL via acquisitions, including the 2009 purchase of Illumination Management Solutions in order to obtain its proprietary LED technology. Cooper opened its LED Innovation Center in 2009 to reduce new product time to market and achieve leverage across businesses.

Hubbell has been acquisitive in an attempt to solidify its position as a top lighting products manufacturer in the US. The purchase of Varon Lighting in 2008 enhanced the company's portfolio of environmentally friendly, energy-saving lighting products.

Siemens has built a substantial lighting business through its Osram Sylvania unit, including recent acquisitions for makers of products related to lighting end markets. The company features integrated LED products across the lighting value chain, from components to fixtures to bulbs.

Zumtobel, a leading Europe-based lighting products company, has selectively acquired smaller firms with products involved in manufacturing LED lighting. The firm views LED technology as a strategic pillar of growth and seeks further expansion of its technical knowledge in preparation for rapid growth in the LED lighting market.

Among other leading electrical-products companies, **Schneider Electric** has emphasized energy-efficient products and solutions, and EEL would be complementary to product lines in adjacent categories. **Toshiba** has a corporate initiative to enhance its lighting systems business through new products such as LED bulbs and fixtures. As a result, the company may be on the hunt for acquisitions within the EEL category. Components manufacturer **Nichia** could look to increase its exposure to the LED market via acquisitions in Asia, a key territory for the LED lighting supply chain. **Samsung Electronics** demonstrated its focus on the sector by establishing Samsung LED in 2009 (through a joint venture with Samsung Electro-Mechanics), with the stated goal of producing the world's best LED. In 2010, Samsung LED and Acuity announced plans to collaborate on solid-state lighting products as a means of accelerating adoption of LED lighting.

Acquisition activity in the EEL category should remain prevalent in 2011 and beyond, based on the market's strong growth prospects and the potential benefits of strategic purchases.

last word

LED lighting begins to mature but must overcome early SSL problems

Like many upstart lighting technologies before it, LED lighting has suffered from broken promises, but quality products are emerging that lighting designers can confidently deploy, says **CHIP ISRAEL** of **LIGHTING DESIGN ALLIANCE**.

The lighting design field is undergoing a transformation and LEDs are leading the way. Historically, we have seen a new, major, and exciting improvement in the lighting field every few years, only to be disappointed with limitations and failures. Hopefully LED lighting will persevere through early road blocks and deliver on its lofty promises.

History, however, is full of problems with new lighting technologies. Remember the introduction of MR-16 lamps to the United States? They worked great in open, European-styled track heads. We borrowed the technology, stuffed them into miniature downlights, and watched as they melted. While that technology is now mature, we still have clients 20 years later that insist on using other lamps. Bad memories fade slowly, even though the technology continues to improve.

Remember the HQI (hydrargyrum quartz iodide) lamp and all that it promised? It was supposed to solve all of the traditional problems with standard metal halide lamps. It failed. But it paved the way to today's ceramic metal halide lamps – a great alternative to incandescent lighting in many commercial applications.

Electronic ballasts for fluorescents and metal halides went through these same growing pains. We experienced 100% failure on one project. Luckily the luminaire supplier stood behind the installation as the ballast manufacturer disappeared. Innovation is sometimes a bumpy road.

Will solid-state lighting (SSL) fail due to the broken promises of early products or find the path to success? There are many issues like binning, heat management and misinformation. We personally have already witnessed projects with 40% failure rates. Our firm has in the past limited the use of LEDs to color applications and low-light needs such as step lights, coves or shelf lighting.

We have daily inquiries from manufacturers promoting their products. Our first request is to see their LM-79 and LM-80 reports. Six months ago, many of them didn't even know about the reports. Currently most have supplied them or are working on it. The high quality manufacturers see the need to self- police themselves so they avoid the mistakes made in the past.

When a manufacturer offers the "equivalency" argument instead of true photometrics, be skeptical. I have heard a hundred times that "we are just like a 50 watt MR-16," only to do a side by side comparison and prove that they are not.

Just recently, we finished testing over 2,000 different LED replacement lamps. There were many bad lamps, for example some that were labeled 2700K but when tested were found to be 6700K. Some fell apart in the boxes while others aimed off axis. The great news is there were more good ones than bad ones. The tide has changed to where major clients can now begin to specify LEDs with confidence. It does take a lot of time to properly select the correct lamp for your application. We have always tried to test or mock-up new technologies and now it is more important than ever.

As designers we must specify LED systems, not a kit of parts. The manufacturers have listened and are now designing new light fixtures around LEDs, not just shoving them into existing fixtures. These progressive designs have integrated minimal architectural-sized apertures with massive hidden heat sinks above. The color temperatures and CRI are now truly appropriate for interior applications. The issues of dimming are being worked out. Manufacturers that originally offered throw-away solutions are now offering fixtures with replaceable components. We are even beginning to see the development of several stock LED driver units which could lead to the standardization of the technology.

Hopefully, we have learned from the past. The future for LEDs is looking bright, but specify thoughtfully and with caution to create the next generation of sustainable and high quality designs.

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