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TECHNOLOGY AND APPLICATIONS OF LIGHT EMITTING DIODES

MR16 SSL
Designs prove 90-CRI performance P.39

Regulations
EcoDesign rules in Europe LED transition P.45

Ambience
Warm dimming technology advances P.55

Transformative Project
Dynamic SSL rejuvenates Birmingham P.33

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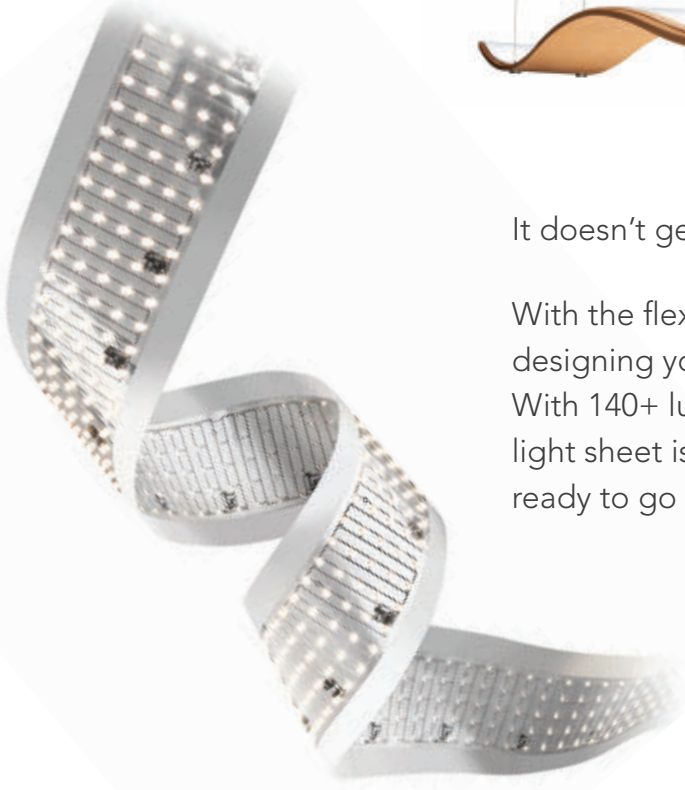

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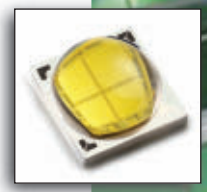

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ISSUE 64

October 2013

Cover Story

Charged with revitalizing a downtrodden railway area in Birmingham, AL, the REV Birmingham organization turned to lighting sculptor Bill FitzGibbons, who highlighted the Art Deco style elements of the "LightRails" project with a mix of Philips Color Kinetics color-tunable luminaires and a controller (see page 33; all images courtesy of Bill FitzGibbons).

features

columns/departments

Color consistency matters, but to whom?

Before beginning to write regularly about the lighting industry five years ago, I was mostly oblivious to the color of white light. To me white was white. I remember buying a BR30 compact fluorescent (CFL) lamp for one of our kitchen downlights, and it was a daylight-like cooler white that was very bright. I was far more enamored with the better visibility on my cutting board than noticing that the lamp looked nothing like the others in the vicinity. My question is how common is that indifference in the world — even in applications such as hospitality where presumably consistency matters? Less onerous consistency requirements would lead to lower-cost LED products and probably more efficient ones with even longer lifetimes.

Now over the past five years, I've spent more than enough time with lighting designers and specifiers to know just how much most of them care about the consistency of lumen output and color. And I'm sure they stress that philosophy with their clients. But I've noticed that many of those clients trade off lower maintenance costs for consistency once the designer leaves the premises.

What prompted this column? Well, I've become a bit of a lighting snob inspecting the technology used in public spaces.

I recently attended the Street and Area Lighting Conference produced by the Illuminating Engineering Society (IES). The conference was at a very nice hotel, the kind of place that you would think would seek consistency in lighting. Especially with the IES coming to town, you would expect that hotel management would make sure the lighting was right. After all, the city of Phoenix even installed new LED streetlights approaching the hotel just as an acknowledgment of the conference.

Outside the main doorways to the convention space, however, I found some lighting in dire need of maintenance. And I don't believe any of it was LED lighting. There was a line of bollards directly across from the doorway in which the light from three successive fixtures looked pink, cold white, and green.

Above a large paved patio in the same area, the ceiling lighting appeared to be four separate fixtures forming something of an artistic-looking chandelier. The grouping directly above the doorway had three warm-white fixtures that looked consistent but a fourth that was a much cooler white. The palm trees lining the walkway to the convention area feature in-grade uplights, but about a third of them were burned out.

I didn't write this column to pick on that hotel that I actually like. And that hotel is not alone. Speakers at The LED Show in Las Vegas back in August lampooned the lighting in the convention ballroom — including some festoon lighting in which the reflection of pixelated LEDs was clearly visible.

My point is simply this: Customers can control the cost of solid-state lighting (SSL) installations by reasonably specifying only the performance level required in a given application. If you are not going to maintain lighting at a consistent color temperature with good color rendering, you shouldn't pay for it. Maybe most guests won't notice. Or have I just happened upon some poor examples of maintenance of late? I'll be interested to see if anyone from the IES conference noticed the things that I did and perhaps comments on this column.

Meanwhile, I look forward to seeing many of you in Munich for Strategies in Light Europe (sileurope.com) in November. Maybe we can inspect some lights together.

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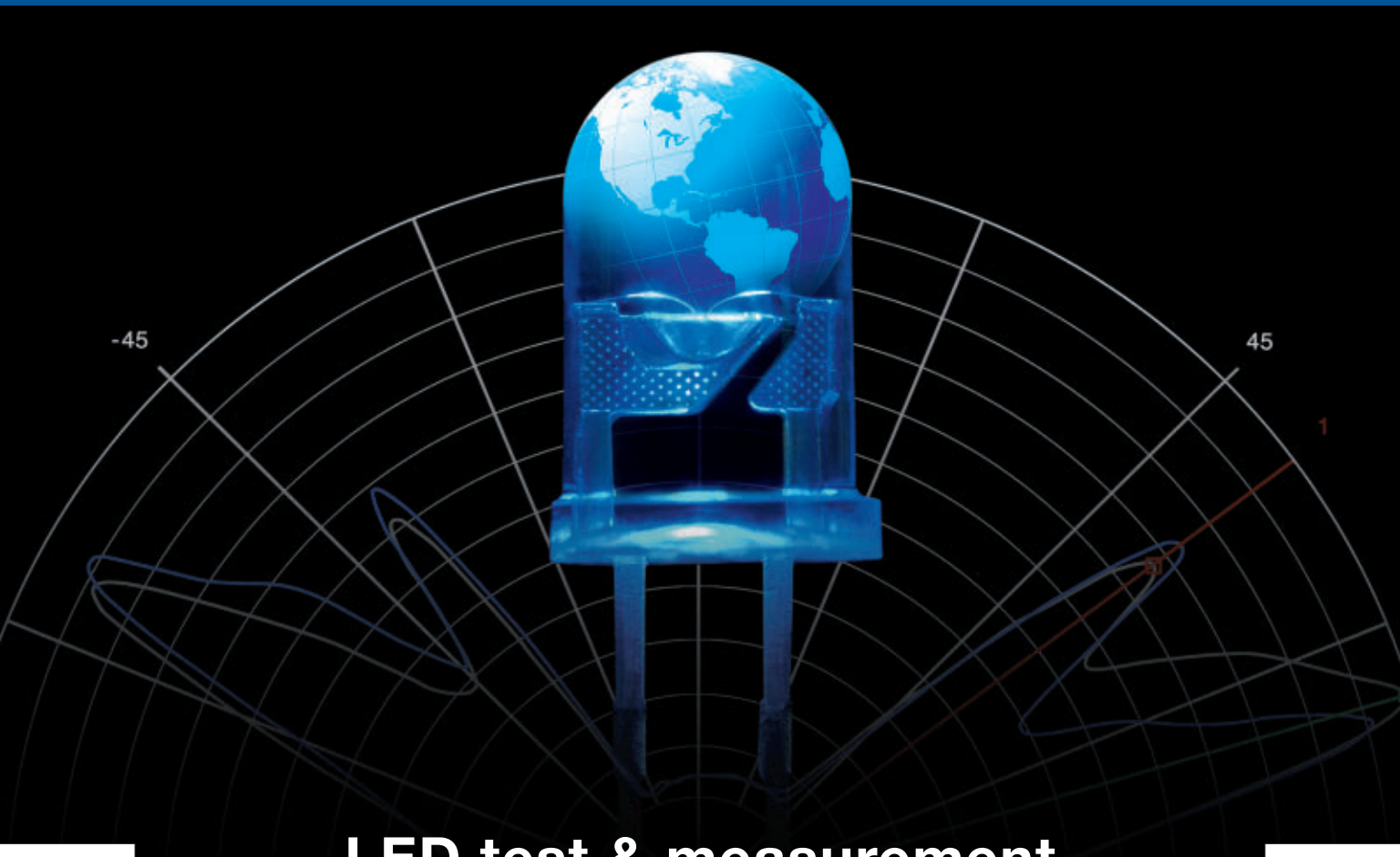

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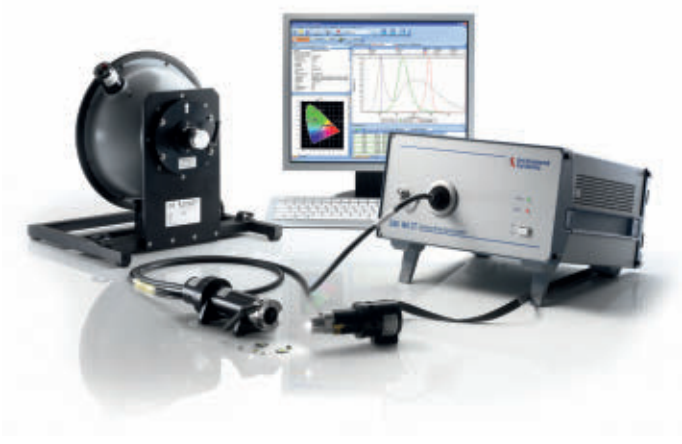

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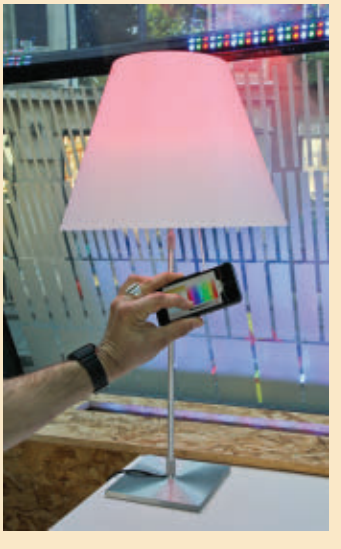
OUTDOOR LIGHTING

GE Lighting supplies Evolve area LED fixtures for Kia front line

Traditionally, lighting the "front line of cars" at an automotive dealership has required metal-halide (MH) lighting because dealers demand high light levels and quality that make the colors pop when customers shop at night. In Columbus, Georgia, Kia Autosport owner Monroe Lee found that his newest dealership could achieve the same results with LED-based GE Lighting Evolve area lights and save 20–33% in energy relative to other lots under the same ownership group.

The Georgia Power utility recommended to Lee that LED lighting might be a viable option for energy savings. "The unique characteristics and improved uniformity of LED lighting allow it to provide superb lighting coverage with fewer lumens and at a fraction of the HID system wattage," said Dave Smolinski, senior market specialist at Georgia Power. "Because this was a new facility, lights and poles could be placed to provide optimum coverage and minimize the number and location of poles in vehicle display areas." LEDs slashed electrical costs from the day the doors opened — among the largest sources of electrical expenses for an auto dealer.

Working together, Lee and Georgia Power selected the low-profile GE Evolve LED Area Lights. The luminaires use concentric reflective rings that help form the desired beam and eliminate light spill. The dealership installed 69 202W LED fixtures mounted on 30 25-ft poles to light the 350-vehicle inventory. Lee chose 4000K CCT lighting with a CRI of » page 10



HUMAN-CENTRIC LIGHTING

Philips LED Hue highlighted in Photon Pod at London Design Festival

The Photon Project is a collaboration of Oxford University and glass engineering company Cantifix studying lighting and wellbeing over four years — an application also known as "human-centric lighting" — and the work was on display at September's London Design Festival. The researchers constructed a glass Photon Pod living space equipped with a variety of color-tunable lighting, including installation of a Philips Hue LED lamp in a table fixture. (For more on human-centric lighting, see "LightingEurope publishes research on LED-based human-centric lighting" on page 27)

The glass pod allowed the public to participate in experiments that characterized levels of alertness and relaxation under different solid-state lighting (SSL) scenarios. The Philips Hue lamp was just one of several » page 10

Kia from page 9 70 and said, "The new LED lighting showcases the cars individually, and really highlights the color of the vehicles on the lot."

The LED lights deliver both energy and maintenance savings. "When compared to a similarly sized dealership that I built five years ago using metal halide fixtures, it appears I'm saving between 20–33% percent on energy costs as a result of the LED lighting," Lee explained. "Plus, I have had no maintenance with the light fixtures since installation a year ago." He anticipates using the same outdoor LED lighting to replace the MH lighting at additional KIA dealership locations. ◄

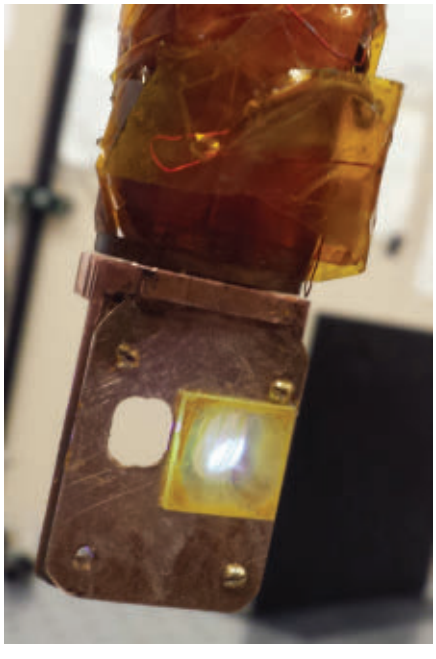
MORE: ledsmagazine.com/news/10/9/17

OLED RESEARCH

Colnatec and Novaled partner, University of Utah pursues white OLEDs

While OLEDs cost more than LEDs and trail in efficacy, researchers and commercial companies continue to pursue OLED technology for SSL applications because of the inherent diffuse, surface-emission lighting properties.

One production angle that promises to cut the cost of OLED manufacturing is roll-to-roll, or continuously-run production lines. Today, most OLED panels for SSL applications are made one small panel at a time. A challenge of continuous processing is accurate control of deposition layers that can be on the order of nanometers in thickness. Accurate measurement is also dependent on the temperature of the sensor used for the measurement and the substrate material.



Colnatec has developed a technique to heat the sensor with accurate control to a known temperature that also reduces stress and relaxes the film on the production line. The partners will now test the heated quartz crystal microbalance (QCM) sensor system that Colnatec calls Tempe.

"Our film-thickness monitoring system, Tempe, was developed to stabilize OLED device performances, for its material characterization capabilities, and for in-situ, self-regeneration properties," said Scott Grimshaw, CTO and co-founder of Colnatec. "At the same time, Tempe has the potential to increase runtime, decrease downtime, and significantly reduce overall costs. We are confident of outstanding results of our system in the continuous OLED production at Novaled."

The work at the University of Utah is much further from commercial deployment. But university research could solve a fundamental challenge that pervades all of SSL technology: direct production of white light.

LEDs either mix emitter colors to produce white light or rely on phosphor. Likewise, OLEDs generally mix red, green, and blue (RGB) pixels to create white light. The implementation can mean additional layers in an OLED manufacturing process.

The Utah team, led by University of Utah physicist Z. Valy Vardeny, was able to develop a single plastic-like polymer that can emit the needed RGB light. Platinum metal atoms inserted at varying intervals along the

Pod from page 9 LED lighting products used in the pod.

"Understanding how people feel in different light settings means applying designed light in ways that harmonize with natural light and benefit people when they're at home, at work — and anywhere else, at any time," said Brent Richards, an architect and the designer responsible for the concept and implementation of the Photon Project pod. "Philips Hue is much more than a lamp with mood settings — it is the tip of the iceberg of what we can do with more dynamic lighting, as the Photon Project will show."

"With Philips Hue, we are only beginning to understand the endless creative possibilities digital lighting will bring," said Sean Carney, Philips chief design officer. "As we acquire new insight into the physiological and psychological effects of light, programmable digital light sources such as Hue will allow us to apply light in ever more meaningful ways…whether supporting our bodies' own natural balance by simulating daylight or achieving something much deeper, promoting feelings of wellness."

The Photon Project began in 2009 and the results were presented at The Photon Symposium held at the London Design Festival. The researchers will move the Photon Pod to Oxford where it will become one of nine pods in a Photon Village that will allow 300 participants to experience what the researchers call "life under glass" and assist in the data collection process.

Friends of Hue

Philips also recently introduced new members of the Hue lighting family, with what the company is now calling Friends of Hue products. The first two products in the family are a 2m LightStrip that can be installed under furniture or in architectural room features, and the LivingColors Bloom fixture that sits on a table or other flat surface and projects much like a floodlight on an architectural facade.

The new Friends of Hue products are designed to work seamlessly with the ZigBee bridge supplied in the Hue Starter Kit, and with Philips and third-party applications developed for Apple and Android smartphones. The new products would be configured just as if they were yet another Hue lamp connected to the local ZigBee network.

Both new Philips Hue products can produce up to 16 million colors. The products can be dimmed, tuned for color, and switched on and off locally and remotely. The lighting products are already available in some stores. ◄

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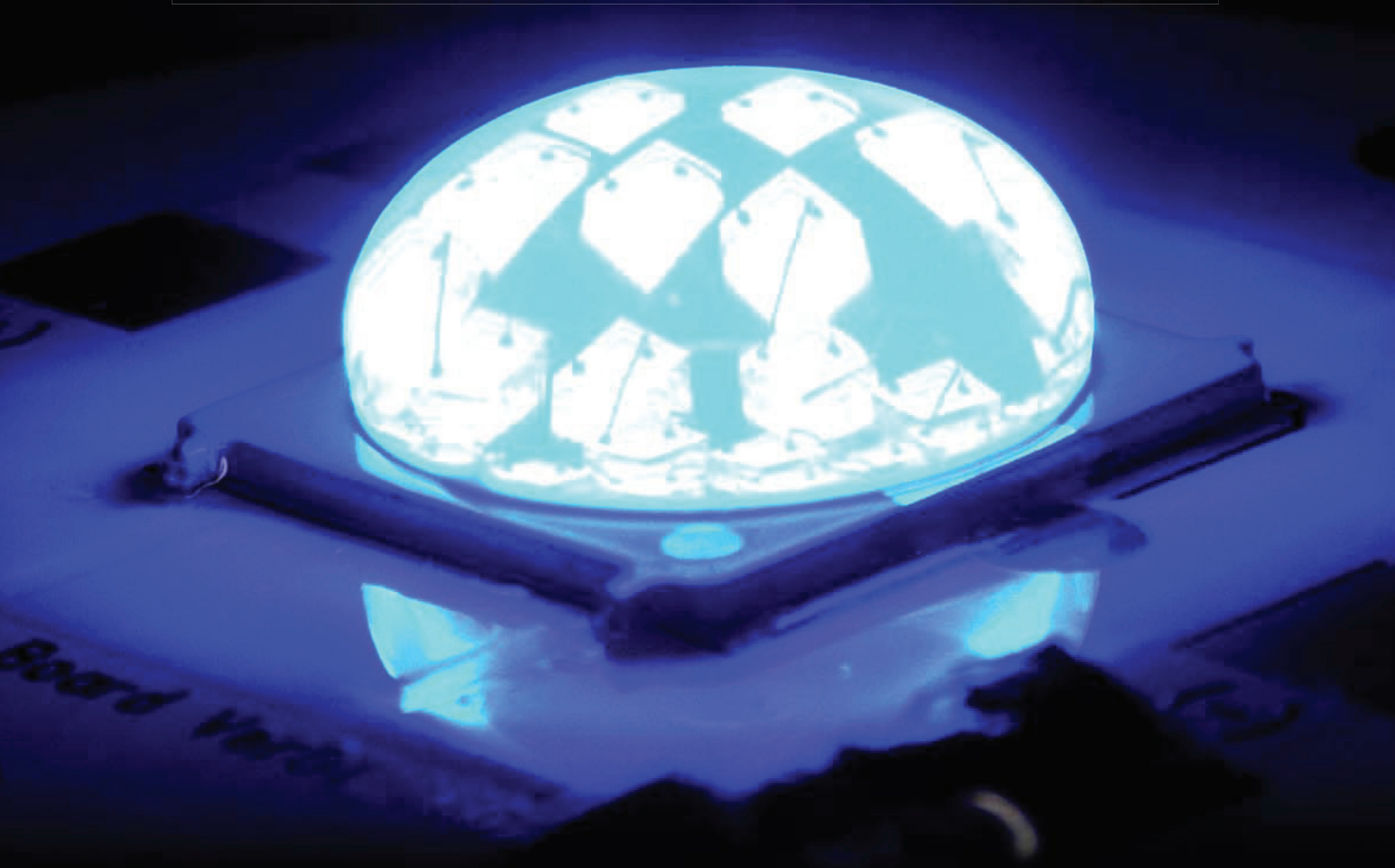

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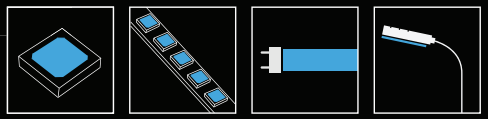

LED PKG / LED MODULE / GENERAL LIGHTING / INDUSTRIAL LIGHTING / OUTDOOR LIGHTING

polymer tune the color emitted. Presumably, such a polymer could produce white light from the multiple colors.

The lab results used light to stimulate the colors on the polymer. An OLED would require electrical stimulation. But Vardeny believes that the work could lead to white OLEDs within two years. The Utah research was in part funded by one of the US Department of Energy (DOE) research grants.

MORE: ledsmagazine.com/news/10/9/10

RETROFIT LAMPS

Cree's new high-CRI LED lamp meets California regulatory spec

Cree Lighting has announced the Cree TW (True White) Series LED retrofit lamps that deliver a CRI of 93 and meet all of the quality guidelines in the latest California Energy Commission (CEC) regulatory specifications. Cree will sell the products immediately in both 40W- and 60W-equivalent versions for $17.97 and $19.97, respectively, in a 2700K CCT that Cree calls Soft White.

The new CEC Voluntary California Quality LED Lamp Specification is a voluntary guideline but could quickly become necessary for lamps to be included in market-incentive programs including utility rebates. The CEC hopes that the guidelines will encourage the development of higher-quality lamps that are more desirable to consumers.

"The Voluntary California Quality LED Lamp Specification was created to move consumers away from inefficient lighting of the past century and toward more efficient LED lighting technology," said Michael Siminovitch, director of the California Lighting Technology Center. "The new Cree TW Series is the first bulb to meet the CA Specification and is exactly what consumers need to see in order to finally transform this marketplace."

Already one utility — the Sacramento Municipal Utility District (SMUD) — has announced plans to provide incentives for buyers of the new Cree lamps. "SMUD sees huge value in reducing the lighting portion of electric bills and is a staunch supporter of the new California LED Quality lighting standard," said Elisabeth Brinton, chief customer officer at SMUD. "We are thrilled to see the first bulbs reach the market. This technical accomplishment makes a huge contribution to energy efficiency, while benefiting consumers with quality lighting."

The new 60W-equivalent lamp delivers 800 lm like the standard Soft White version. Cree rates it for a 25,000-hour life and offers a ten-year warranty. Home Depot has the products available for sale immediately.

MORE: illuminationinfocus.com/news/4/9/6

Osram Sylvania launches 2500K LED lamps for hospitality settings

Osram Sylvania has announced a new line of Ultra 25 LED lamps that features a very warm color temperature for inviting moods and that includes lamps for most of the popular sockets utilized in hospitality settings. The announcement includes B10, B13, BR40, PAR20, PAR30, and MR16 LED lamps that can deliver ambient, accent, and decorative lighting. Sylvania has also expanded the Ultra SE SSL family that includes incandescent-like, dim-to-warm-CCT capability.

In particular, Sylvania expects the Ultra 25 lamps to find use in restaurants, hotels, and casinos, providing both more efficient lighting and a soothing atmosphere. "Business in the hospitality industry are always interested in reducing energy but are also just as focused on creating a mood that entices repeat customers," said Ellen Sizemore, product portfolio manager for LED lamps at Sylvania. "Incandescent lamps have offered the desired warm color but at the cost of higher electricity bills."

Sylvania says that the new Ultra 25 lamps family will offer up to 86% energy savings over incandescent lamps. The entire Ultra 25 family is dimmable to 10% using legacy triac dimmers. The lamps should last ten or even more times as long as incandescent lamps — reducing disruptions for maintenance in hospitality settings. The lamps are rated for 25,000 hours of life.

MORE: illuminationinfocus.com/news/4/9/9

GE Lighting launches 90-CRI LED lamps in Reveal line

GE Lighting has long used the Reveal brand as an indicator of premium-performance light bulbs that do a superior job of color rendering relative to the company's mainstream portfolio. Now the company has begun selling LED-based retrofit lamps in the Reveal SSL family offering 90-CRI color performance across 40W- and 60W-equivalent A19 lamps and a BR30 lamp.

Retailer Home Depot has the 11W Reveal LED lamp that is a 60W equivalent priced at $19.97, and the 12W BR30 lamp that is a 65W equivalent priced at $26.97. Like other 90-CRI or higher products, the Reveal lamps carry a price premium compared to many other LED lamps. (See Cree's 93-CRI version of its A19 60W-equivalent lamp to the left).

While the prices may be on the high side, there is surely a market for the high-CRI products. Ultimately the key point is that customers who want the best light quality can now also get the longest-life and low-energy technology in the same product enabling SSL usage in more places. The 60W equivalent lamp delivers 570 lm, the 40W equivalent lamp delivers 360 lm, and the BR30 lamp delivers 630 lm. In the case of the A19 lamps, those output flux specifications are a bit lower than the presumed incandescent equivalents would deliver. Still, the quality will be more important than the light output in the case of the Reveal brand.

All of the Reveal LED lamps come in a 2700K warm-white CCT. The rated lifetime is 15,000 hours for the 60W-equivalent A19 lamps and 25,000 hours for the other two products.

MORE: illuminationinfocus.com/news/4/9/12

Cree's $10 LED lamp receives Energy Star qualification

Cree has earned Energy Star qualification for its soft-white Cree LED bulbs, signifying

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Tape available

LL01LU-AIK45135L02
LxWxH(mm) 18 x 12.5 x 7.05
FWHM 45°x135°
Cree XP-G2
Lumileds Rebel ES
Nichia NCS19, NVS19, NVS19B

LL01LU-UQ70140L02
LxWxH(mm) 18 x 11 x 6.6
FWHM 70°x140°
Cree XP-G2, XT-E
Lumileds Rebel, Rebel ES
Nichia NVS19B

LL01CR-PB70140L02
LxWxH(mm) 22.4x 11.4 x 6.9
FWHM 70°x140°
Cree XB-D, XP-G2, XT-E
LGIT Ceramic 3535
Nichia NVS19B

AREA LIGHTING

LL01CR-HQxxL06-M2
DxH(mm) 16 x 10.3
FWHM 12° 15° 18° 25° 35° 45° 15° x 28°
Full angle 20° 25° 30° 40° 60° 80° 25° x 45°
Cree XP-E2, XP-G2
LGIT Ceramic 3535

Tape available

LL01ZZ-EXxxL06-M2
DxH (mm) 22.2 x 9.7
FWHM 8° 15° 25° 35° 55° 15° x 30°
Full angle 12° 25° 40° 60° 80° 110° 30° x 65°
Cree XP-E2, XP-G2
Lumileds Rebel, Rebel ES
LGIT Ceramic 3535

DF/BDF/AAF Series


Tape available

1. Cree XP-E2, XP-G2
2. Cree XBD
3. Lumileds Rebel, Rebel ES
4. Nichia 119A, 119B
5. Nichia 757
6. Osram Oslon Square
7. LGIT Ceramic 3535

		FWHM	Full Angle
1 4 7	**LL01CR-DFxxL-M2** DxH (mm) 13.5 x 7.35	15° 25° 40° 45° 60°	25° 40° 60° 80° 100°
3	**LL01LU-DFxxL-M2** DxH (mm) 13.5 x 7.35	15° 25° 40° 45° 60°	25° 40° 60° 80° 100°
2	**LL01CR-BDFxxL-M2** DxH (mm) 13.5 x 7.35	40° 60°	60° 100°
1 4 7	**LL01HS-AAFxxL-M2** DxH (mm) 13.5 x 7.35	25° 40° 60°	40° 60° 100°
5 6	**LL01OS-BDFxxL-M2** DxH (mm) 13.5 x 7.35	40° 60°	60° 100°

Angles are measured with different specific LEDs and please contact us for more details.

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that the bulbs qualify for incentive rebates through certain local utilities. The soft-white 60W incandescent replacement consumes just 9.5W, while delivering light output of 800 lm. The 40W incandescent replacement in soft white delivers 450 lm and consumes only 6W.

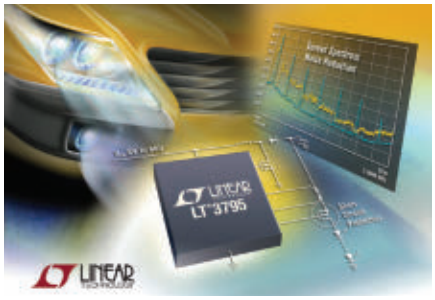
"Energy Star qualification can enable the Cree LED bulbs to be purchased with an instant utility rebate, delivering consumers a quality LED bulb for under $5," said Chuck Swoboda, Cree chairman and CEO. "Cree's already affordable bulb combined with utility rebates makes switching to LED lighting an easy choice for consumers."

DRIVER ICS

TowerJazz and DMB launch AC driver, Linear Tech offers 110V controller

Linear Technology has announced the LT3795 DC/DC converter IC designed to drive LEDs with support for string voltage as high as 90V. Contract IC fabricator TowerJazz and DMB Technology have announced an AC LED driver IC that the latter will sell, providing broader access to AC-drive technology for SSL applications.

The Linear Technology LT3795 driver IC uses a technique called spread-spectrum frequency modulation to spread the electromagnetic interference (EMI) over a relatively broad spectral band, thereby



reducing the peak energy in any narrow band, and helping SSL products meet electromagnetic compatibility guidelines. The IC can operate from DC inputs ranging from 12V to 110V, deliver output voltages as high as 90V, and serve power loads up to 50W.

The new IC can be utilized in buck, boost, buck-boost, and SEPIC DC/DC-converter topologies. An internal PMOS switch driver provides short-circuit protection, and enables pulse-width modulation to support dimming over a 3000:1 range. The IC can also support simple 10-step dimming for 0–10V applications.

In the AC-LED segment, most AC-LED technology to date has been sold in modular form with companies such as Lynk Labs and Seoul Semiconductor supplying modular light engines that include any required electronics. The latest announcement from TowerJazz and DMB Technology will bring the relatively simpler AC-driver technology to the broader SSL product-developer market. DMB Technology will sell the driver IC that was enabled by the 700V BCD (Bipolar-CMOS-DMOS) platform that TowerJazz has perfected for analog and mixed-signal ICs.

The question remains as to whether the AC-driver can match the efficacy of DC-driven LEDs or deliver on the flicker and EMI issues that have been associated with the technology. We covered some of that ground reporting on a session at The LED Show focused on the latest in LED components (ledsmagazine.com/features/10/9/1).

DMB Technology believes that the design has overcome the flicker problems associated with some AC-LED implementations. "Our AC direct LED driver IC product using TowerJazz's 700V BCD process is receiving very good reviews in terms of product efficiency and superior flicker function, which is more advanced than other similar products presently on the market," said Dong-Youl Jeong, DMB Technology's CTO.

MORE: ledsmagazine.com/news/10/9/13

PATENTS

Intematix announces green aluminate phosphor patents

Intematix has announced US patent numbers 8,529,791 and 8,475,683 that apply to yellow- and green-emitting, garnet-based phosphors. The patents include IP that could be applied in both general lighting applications and in display backlighting.

The green aluminate (GAL) phosphors can be combined with red phosphors to enable lighting with high CRI. "By using our GAL phosphors, LED solutions may be designed for efficient performance at CRIs greater than 90," said Yi-Qun Li, chief technology officer at Intematix. The company said it has demonstrated CRIs as high as 98.

High CRI is especially important in applications such as retail and hospitality and in some cases is mandated by market-incentive programs. Intematix's Li added, "This technology is instrumental to meeting new standards like California's Quality LED Lamp Specification."

MORE: ledsmagazine.com/news/10/9/15

Nichia wins round in LED IP battle with Everlight

Nichia and Everlight Electronics have battled around the globe over IP and patents and specifically Nichia's widely cited phosphor patent for producing white LEDs commonly referred to as the YAG (yttrium aluminium garnet) patent. Recently, a Düsseldorf District Court in Germany has ruled that Everlight and its distributors Future Electronics and REGO Lighting have infringed the YAG patent.

Apparently the defendants will owe Nichia damages. And the court has ordered the affected LEDs to be recalled and destroyed. The injunction is permanent but is also appealable. Everlight had asked the court to delay the infringement case until the German Federal Patent Court had ruled on Everlight's contention that the YAG patent should be nullified. That request wasn't granted but the nullity action will still be heard.

MORE: ledsmagazine.com/news/10/9/6

BUSINESS

FTC vs. Lights of America

The Federal Trade Commission (FTC) has won a $21.2 million ruling against LED lighting wholesaler Lights of America with the US Federal Court ruling that the company falsified claims of light output and lifetime of LED retrofit lamps. Legal news source Law360 reported that Lights of America made $21.2 million in wholesale revenue offering LED lamps through various retailers while knowing there was scientific evidence that contradicted the claims of lifetime and light output.

As we reported back in September 2010, the false claims of light output and lifetime were the basis for the original action by the FTC (ledsmagazine.com/news/7/9/6). That court action, among other false claims early on in the SSL industry, led to consumer protection in the form of programs such as the separate Lighting Facts programs administered by the FTC and the US Department of Energy (DOE).

The latest ruling came from the Central District of the California Federal Court. The next steps are unclear given the complexities of the US legal system. The FTC has been charged with submitting a proposed judgment for compensating buyers of the products. There is also a class action lawsuit against the company; at press time it was scheduled to be heard by the California Federal Court on October 7.

MORE: ledsmagazine.com/news/10/9/15

PACKAGED LEDS

Cree launches 1.6×1.6-mm LED family delivering 287 lm

Cree has announced another small-footprint LED in its XLamp family of ceramic-packaged products designed for general lighting

applications. The 1.6×1.6-mm XQ-E family comes in a package that is geometrically consistent with products such as the XT-E/E2 LEDs, delivers a 110° viewing angle, and is offered in white, red, green, and blue versions enabling a broad set of target applications.

Paul Scheidt, Cree product marketing manager, said that the new XQ-E LED offers nearly double the lumen density compared to the XP-G2 that had previously been Cree's top-performing LED measured in lm/mm^2. The new LED die is carved from the same wafer as the XP-E2 LED family that is based on Cree's SC^3 (pronounced SC cubed) manufacturing platform. The white versions of the XQ-E come in 2700K to 5000K CCTs with 80 CRI available in all but the coldest version and 70 CRI offered across the product line. At 1A of drive current and 3W of power the LEDs deliver 287 lm.

With the XQ-E family, luminaire makers can deliver more compact RGB products. Even in applications such as a light engine for a white-light directional lamp or luminaire, the size could come into play. Scheidt showed an example of a light engine with nine XP-G2 LEDs in an array. To achieve the same flux output you would need 18 XQ-E LEDs. But those 18 LEDs would fit in 50% of the footprint of the XP-G2 LEDs.

MORE: ledsmagazine.com/news/10/9/18

Philips Lumileds announces Luxeon Q LED, pushes efficacy

Philips Lumileds has announced the Luxeon Q family of phosphor-converted white LEDs in a 3.5×3.5-mm package, based on the blue die that the company announced last February. The company said that the epitaxy technology combined with light extraction and conversion enhancements at the die, phosphor, and package level deliver industry-leading efficacy for SSL products.

Lumileds' prior-generation of die was based on thin-film flip-chip technology in which the sapphire layer was removed in the back-end manufacturing process. The new flip-chip die leaves the sapphire in place. Increasingly, patterning in the sapphire substrate is used to maximize light extraction; Lumileds used some form of that with the flip-chip die.

The Luxeon Q family spans the range of 2700K to 5700K CCTs. The warmer-white LEDs have a CRI of 80 whereas the members with CCT of 4000K and above have a CRI of 70. Lumileds will offer the LEDs in 3- and 5-step MacAdam ellipse bins.

"Our LED is especially competitive when it's driven harder," said Kathleen Hartnett, product line director. "For instance, at 1 Ampere, a flux of more than 300 lm at an efficacy of 102 lm/W at 85°C is achieved in neutral white at 4000K."

MORE: ledsmagazine.com/news/10/9/14

LED MODULES

GE Lighting expands the LED Infusion module family

GE Lighting has announced the Gen3 family of its Infusion LED modules that include the Infusion Spot Light Module, the Infusion Down Light Module, (DLM) and the Infusion Narrow Punch Module (NPM). The third-

generation family offers improved efficacy and a broader choice of lumen packages and beam spreads relative to Gen2 products.

The Gen3 family includes models ranging from 850–4500 lm, with the entire range available in the Spot Light Module family. The products are offered optionally with a CRI greater than 90 to support retail and hospitality applications.

The DLM family is available in 1000–4000-lm versions with a CRI above 90. Efficacy on the products hits 80 lm/W across the range from 2700K–4000K CCTs. The NPM family includes fewer options with flux ranging from 1100–1500 lm, and CRI ranging from 80–87.

GE Lighting said the company is now offering module-to-module color consistency within a 2-step MacAdam ellipse — critical for lighting manufacturers that need to ensure the consistency of their end products over time.

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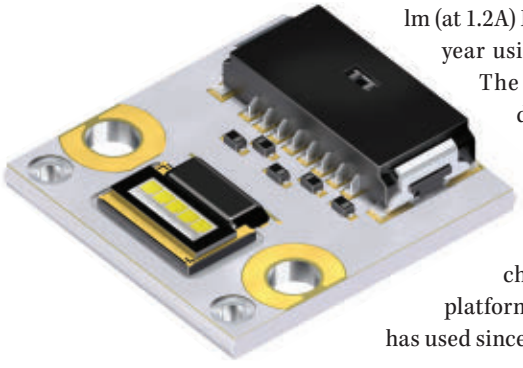
AUTOMOTIVE

Osram introduces two new LED families for automotive headlamps

Osram Opto Semiconductors has announced two new LED families for forward-facing automotive exterior lighting applications including headlamps. The Oslon Black Flat family is a compact design in a surface-mount-technology (SMT) package that can be soldered directly to printed-circuit boards (PCBs). The Ostar Headlamp Pro family includes five emitters and targets usage in adaptive headlight scenarios where individual LEDs can be extinguished or dimmed based on traffic and road conditions.



The new Oslon Black Flat LED is a follow on to a 270-lm (at 1.2A) LED announced last year using the same name. The new two-emitter design can deliver 500 lm at 1A. The LED is based on Osram's UX:3 thin-film flip-chip manufacturing platform that the company has used since 2011. The new two-chip device measures 3.1×3.75 mm, and the slim design allows flexibility for usage in a variety of forward-facing lighting applications. The SMT package will also enable broad usage because it enables simple, low-cost assembly and is handled similarly to other electronic components.

The new Osram Ostar Headlamp Pro products target what the industry often refers to as Advanced Forward Lighting Systems (AFS). The new version of the LED enables individual control of the five emitters. The control comes via the connector integrated onto the LED. The new LED can deliver a maximum of 710 lm at 500 mA. Each of the emitters measures 1×1 mm. The overall package dimensions are 20×21 mm.

MORE: ledsmagazine.com/news/10/9/12

COB LEDs

Cree doubles lumen density in 9-mm COB LED family

Cree has announced the latest member of its chip-on-board (COB) LED array family with the CXA1520 delivering 2000–4000 lm from a 9-mm light emitting surface (LES). The company is targeting the new LED for replacement of high-output ceramic metal-halide (CMH) sources that are regularly used for directional accent lighting when halogen lamps can't deliver sufficient light levels.

Cree calls the new LED array a high-density product, referring to the fact that more die are packed into the 9-mm area, although the application is also an SSL product that delivers high-density beams. Cree product marketing manager Paul Scheidt said that the CXA1520 is the only COB LED array on the market at 9 mm that can deliver the 40,000-cd center beam candle power (CBCP) required of a replacement lamp for PAR30 CMH sockets. He added that the new array offers double the lumen output of competitors' products and prior Cree products with the same LES.

The addition of the CXA1520 gives directional retrofit lamp makers considerable scalability to use the same basic lamp design and serve a breadth of applications. Scheidt said a manufacturer could use the same optics to realize a 75W-halogen-equivalent lamp with the CXA1507, a 100W-halogen- or 20W-CMH-equivalent lamp with the CXA1512, or the new LED for the 39W-CMH-equivalent lamp.

Such a family would require higher-current drivers as the lumen package goes up, and perhaps an enhanced thermal design. But Scheidt said that the optics design is the most time consuming in a retrofit lamp project and that "nearly the exact same design supports a range of products."

MORE: ledsmagazine.com/news/10/9/11

Bridgelux introduces more compact COB LEDs for retrofit lamps

Bridgelux has expanded its lineup of COB LEDs with the new V Series that come in V6 and V8 models with a 6- or 8-mm LES, respectively. The V Series is targeted at sub-1000-lm applications including directional retrofit lamps and other SSL applications that require tight beam control such as security, track, spot, and accent lights.

"These small LED packages are well suited for low-lumen applications and will help accelerate the migration from traditional light sources, such as incandescent and halogen, to cleaner, more

efficient solid-state lighting," said Max Hong, chief sales and marketing officer of Bridgelux. "We leveraged many technological advances from our industry-leading Vero LED Array Series to bring our high-quality light engine technology to the V Series for lower-power, cost-sensitive applications."

Simplicity at the system level can drive broader uptake of LEDs in lighting, especially if efficacy is near what can be achieved with single-die LEDs. The V Series efficacy varies based on drive current, CRI, and other factors, but a 3000K LED with 80 CRI delivers 118 lm/W at nominal drive current — which is 175 mA for the 23.7V device under discussion.

Bridgelux offers the V Series in a variety of electrical configurations with forward voltage varying from 17.8V to 35.6V. Likewise, the LEDs are available over a range of 2700K to 5000K CCTs with warmer LEDs offered with CRIs of 80 and 90, and 5000K LEDs also offered in 70-CRI versions.

As has been the case with a number of recent LED announcements, Bridgelux stressed the performance of its products at higher driver-current levels that are typical in product designs today with more reliable LEDs and exhaustive LM-80 testing. The efficacy on the LED mentioned previously drops only to 97 lm/W at double the nominal current.

MORE: ledsmagazine.com/news/10/9/20

ACQUISITIONS

Veeco buys Synos to support OLED manufacturing

Veeco Instruments has announced the acquisition of Synos Technologies. The Synos Fast Array Scanning Atomic Layer Deposition systems can reduce OLED manufacturing cost.

"We have found a great fit to add to Veeco's technology portfolio and expand our growth opportunities," said John R. Peeler, Veeco's chairman and chief executive officer. "Synos is an early stage company with big growth potential. We believe that their fast-array scanning ALD technology for thin-film encapsulation layers will remove the primary barrier to adoption of flexible OLED displays, helping make unbreakable, lightweight mobile displays a reality." The company expects to ramp OLED production using the technology in 2014.

NETWORKS

SSL Network controls again take spotlight at SALC opening

Edward Smalley, the Illuminating Engineering Society (IES) 2013 Street and Area Lighting Conference (SALC) Committee Chair, convened the keynote session of the conference and said that with LED-based outdoor lighting you no longer need to compromise in terms of energy efficiency, lifetime, or lighting quality. The theme ran through the opening speeches that LEDs offer good efficiency, but that it is networks and controls that can truly allow cities and municipalities to maximize

energy and maintenance savings with SSL.

Mark Lien, director of government and industry relations at Osram Sylvania, listed ten outside industry associations and standards bodies that are exerting force on the SSL industry and noted that five are focused on interconnect. Examples include the ZigBee Alliance, the TALQ Consortium, and the Connected Lighting Alliance. Lien said, "Interconnectedness is the common thread."

Light quality has also moved beyond source efficiency in importance. Naomi Miller, lighting designer at the DOE Pacific Northwest National Laboratory (PNNL), said that LEDs are sufficiently efficient that we can afford to waste some of that efficiency now to build better, more comfortable lighting products.

Gianni Minetti, president and CEO of Paradox Engineering, said 1.2 million new people are moving into new cities each week around the globe. Cities must become more efficient to sustain this growth. He emphasized that smart-city technology, including networked intelligent lighting, could improve energy efficiency by 30% in the next 20 years. That improvement comes on top of more efficient light sources.

MORE: ledsmagazine.com/news/10/9/5

Silver Spring and Sunrise Technologies partner for lighting networks

Silver Spring and Sunrise Technologies used SALC as a venue to announce their partnership in the controls area. Silver Spring is a well-established company in supplying network technology used by utilities to read digital power meters. The company has been trying to enter the lighting networking space.

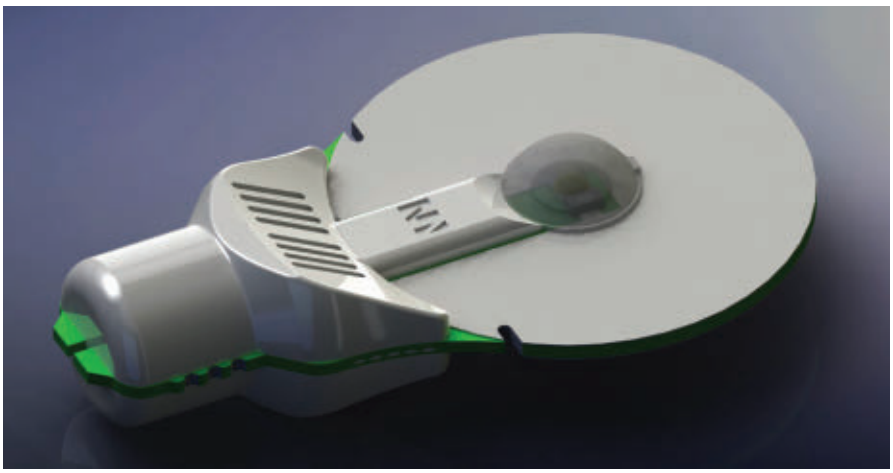
Sunrise is a leading vendor of the photocells that are often attached to the top of streetlights to automatically turn the lights on at night and off in the morning. The two companies are planning to integrate the Silver Spring network technology into new versions of Sunrise control modules. Presumably, streetlights equipped with such modules would connect seamlessly using existing installed Silver Spring networks.

"Silver Spring and Sunrise Technologies' proven technology and extensive experience with the world's largest utilities makes us natural partners to help utilities, municipalities, and other streetlight operators control costs, improve efficiencies, and create safer cities as they modernize their public lighting systems," said Sterling Hughes, the senior director of advanced technologies at Silver Spring Networks. "The industry is definitively moving toward general-purpose IP networks powering multiple applications and we are proud to extend our smart city platform with Sunrise Technologies."

RETROFIT LAMPS

NliteN startup announces novel approach to LED retrofit lamp

NliteN has announced an LED retrofit lamp called the 2D-Lite LED Disk that the company says can hit the $10 price point for consumers in 2014 for an 800-lm, 60W-equivalent lamp.



The single PCB that hosts the LEDs and driver electronics is shaped in that form. The design eliminates interconnects between the LEDs and driver electronics, and the metal-plated PCB acts as both a heat sink and reflector. It uses two COB LEDs that are mounted back to back on either side of the PCB. A COB LED alone wouldn't provide an omnidirectional beam pattern. You often see a collimating total internal reflection (TIR) lens used with smaller LEDs, but that is to narrow the beam pattern and wouldn't work with a larger COB. But in this case a dispersion lens is used to broaden the pattern and the reflective surface of the PCB adds to the beam spread.

The 2D-Lite design would be assembled automatically on a surface-mount line. There are no wires requiring connections or hand soldering/assembly. Even the screw base of the lamp is implemented in part within the confines of the PCB. The plastic portion of the base that is evident in the photo does not have the Edison socket threads and is smooth. But you will see the Edison threads on each side of the PCB (the green vertical equator along the base).

Despite the positives, NliteN faces an uphill challenge to bring the 2D-Lite design to market. The company needs funding to begin volume manufacturing including the expensive mold for the injection-molding required to build the plastic base. The company is trying to raise money on the Indiegogo social-funding site, and is part of the Philips Innovation Fellows program on that site.

The other challenges include the nontraditional look of the lamp and the relatively short time left for companies to capitalize in the retrofit lamps space. It wouldn't be terribly difficult to put a globe on the NliteN design, although that would impact the cost and possibly the thermal design.

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Philips Lumileds CEO moves to expand breadth of LED offerings

ELLA SHUM interviews Philips Lumileds CEO Pierre Yves Lesaicherre, asking tough questions about the increasingly competitive LED market, Lumileds' plans for the future, and the challenge of serving a vertically-integrated lighting manufacturer and the commercial market.

Preparing for the Strategies in Light (SIL) Japan conference, Strategies Unlimited packaged LED analyst and conference chair Ella Shum had a chance to ask Philips Lumileds CEO Pierre Yves Lesaicherre about the solid-state lighting (SSL) market, LED technology, and what Shum calls the "mommy dearest" relationship between Lumileds and parent Philips Lighting. Lumileds's senior director of segment marketing Ray Chock will expand on these themes in a SIL Japan keynote on October 17, 2013 (sil-ledjapan.com).

ELLA SHUM *is chair, Strategies in Light Conferences, Strategies Unlimited Partner, YEBY Associates LLC.*

LEDs Magazine: Since you came aboard, Lumileds seems to be in different spirits, which shows up in the new products. Can you talk to us about the changes that have taken place since January 2012?

Yves Lesaicherre: Lumileds has always been a technology leader and innovator in LEDs. In order to accelerate the rapid adoption of LEDs and strengthen Lumileds' position as an industry leader, we embarked on several key steps. 1) Expanding the Lumileds product portfolio to serve all lighting applications. Specifically, this meant also developing and offering mid-power and low-power LEDs, in addition to our leading high-power LED portfolio, and also expanding into flip-chip die sales. 2) Increasing investments in R&D to accelerate the number of products introduced to the market. 3) Adding deep semiconductor expertise to complement existing LED expertise, in order to drive world-class operational efficiency and cost improvements. 4) Growing our go-to-market channels by expanding the distribution network. 5) Launching several significant IT upgrades to ensure Lumileds has a world-class IT infrastructure.

LEDs Magazine: What is Lumileds' strategy in LEDs for lighting?

Lesaicherre: Lumileds intends to be the best LED supplier for lighting customers and is accomplishing this by offering a comprehensive portfolio of LEDs for lighting applications with over 130 products introduced in 2012 and over 250 targeted in 2013, offering the highest-efficacy LEDs such as Luxeon T and Luxeon M that are lm/W leaders; developing application-specific LEDs optimized for each application such as Luxeon M for outdoor, Luxeon S for retail Ceramic Discharge Metal-Halide (CDM) spot replacements, mid-power for A19 lamps, and low-power for [linear T8 replacements]; and providing the most complete applications and technical support to help customers develop optimal lighting fixtures. We have also strengthened our focus on Asia, and especially on serving the fast growth markets such as Japan, China, and Korea.

LEDs Magazine: How do you see the LED lighting market in three years? Many new players? Consolidation to a few big players?

Lesaicherre: We believe that the LED industry will indeed consolidate to a few large players who provide best-in-class efficacy, have a full portfolio of LED products for all major lighting applications, have manufacturing scale to provide cost reductions, and who truly understand the needs of lighting end users. In accordance with this, we continue to make strong investments in R&D to deliver a ~15% improvement in lm/W annually, have rapidly grown our product portfolio, and continue to deliver LEDs optimized to specific applications while significantly expanding our production capacity.

As the LED BOM [bill of materials] cost becomes a much smaller percentage of the overall system cost, LED unit cost reductions will become less important and differentiation will be driven by lm/W performance, which in turn will become much more critical. Lumileds will continue to make investments to deliver the highest lm/W in the industry.

Finally, most lighting segments today have only single-digit adoption of LEDs, so there is a huge growth opportunity ahead for the entire industry. In addition to higher penetration of LEDs into traditional lighting applications, we will also see several new innovative applications such as color tunability, intelligent controls, smart sensing, and connected lighting.

LEDs Magazine: LEDs are becoming a commodity. How does Lumileds see this trend toward commoditization?

Lesaicherre: A commodity product is one that has very little to no differentiation in the market and there is little supplier preference. LEDs are far from this state. LEDs are in fact becoming more specific to the application and require customization to best meet the needs of the specific lighting design. As examples, Lumileds developed Luxeon M targeted to outdoor applications and Luxeon S targeted to spotlights and CDM [replacements] — both have seen tremendous customer adoption and market success.

Even in commodity-like products such as mid-power, there is a premium in the market for higher performance; in fact, sophisticated customers prioritize better LED performance over lower unit cost. We intend to be a performance leader and will continue to drive differentiation in mid-power and low-power by supplying the most efficacious products.

LEDs Magazine: When I commented on the different strategies of the top LED companies, Lumileds was awarded "mommy dearest" status. What is the relationship with Philips Lighting? How do you balance the needs of internal and external customers?

Lesaicherre: Both Philips Lighting and Philips Lumileds are in absolute agreement that for Lumileds to be truly successful, Lumileds needs to have global scale and serve the entire market, not just Philips Lighting. Accordingly, for years Lumileds has served a truly global customer base in every region, several of whom are competitors of Philips Lighting. We will continue with this strategy of serving the entire lighting market.

To protect the confidentiality of both our global customers and of Philips Lighting, Lumileds has for several years maintained separate sales and applications support teams for these groups. There is a dedicated sales and applications support team to serve our global customers, and a separate dedicated team to serve Philips Lighting; these teams do not communicate or share any information with each other. We have successfully maintained this separation for several years to protect the confidentiality of all our customers. Proof of success lies with our hundreds of customers who choose Lumileds as their primary LED supplier in spite of these customers competing with Philips Lighting. We are committed to maintaining this way of operation and successfully serving a truly global and diverse customer base.

LEDs Magazine: While lighting always dominates the scene, Lumileds is one of the top players in camera flash and automotive LEDs. Can you talk about your product strategy in those two segments?

Lesaicherre: Since the founding of Philips Lumileds in 1999, automotive lighting has been one of the focus areas for Philips Lumileds. We pioneered the first wave of AlInGaP [aluminum indium gallium phosphide] LEDs with SnapLED and SuperFlux products and InGaN [indium gallium nitride] LEDs with Luxeon K2 and Luxeon

Rebel, which enabled never-before-possible automotive LED functions such as [brake] lights and daytime-running lamps [DRLs].

Our passion for LEDs, combined with Philips' extensive knowledge in automotive lighting, has enabled us to offer LED packages that are designed from the ground up to exceed automotive requirements in terms of performance and reliability. In the next 12 months, Philips Lumileds will introduce a series of mid- and high-power automotive LEDs that will give our customers the flexibility they have always desired from the light source to achieve new and unique styling themes.

Luxeon F will offer all the high-performance aspects of Luxeon Rebel but with a package that is one-third the size of Luxeon Rebel and only half of the thermal resistance, targeting light-guide DRL and front turn signal, distributed low and high beam, matrix beam, and cost-effective front fog functions. We will also introduce the next-generation Luxeon Altilon with a performance exceeding 1000 hot lumens. With a focus on high performance at the stringent operating conditions in an automobile, Luxeon F and Luxeon Altilon will be the first automotive LEDs binned hot, which will greatly simplify customers' design processes.

Lumileds will also introduce new proliferations of SnapLED in red-orange and SnapLED Xtreme in Q3. SnapLED Xtreme offers a unique oval-batwing radiation pattern with an average of 45 lm, and will enable cost-effective, homogenously-lit tail function with the fewest number of LEDs. Finally, we will launch a surface-mount red-orange PLCC4 package with a low thermal resistance of 40K/W, high junction temperature of 135°C, and a minimum flux of 18 lm.

Lumileds is the leading supplier of LEDs for flash applications and continues to innovate in this area. Some of our recent product innovations include achieving greater than 300 lm while maintaining the best color over angle and lumen density in the industry, and enabling thinner LEDs and flash modules that enable our customers to achieve new, thinner form factors for their smartphones.

LEDs Magazine: What is Lumileds' strategy in Asia, especially in China, which is one of the biggest markets in the world?

Lesaicherre: Lumileds recognizes that the fastest-growing LED markets are in Asia, especially in China and Japan. As you may be aware, Lumileds has historically had a significant manufacturing footprint in Asia with a state-of-the-art wafer fab in Singapore and two back-end LED packaging factories in Penang, Malaysia.

Recently, we have significantly expanded our go-to-market channels in China and the rest of Asia by partnering with several leading, world-class distributors. We have also expanded our product portfolio to include products specifically targeted for the Chinese and Japanese markets. Finally, we have also significantly expanded our technical expertise in China by establishing a team of development engineers in Shanghai who support our customers with design expertise in optics, electronics, thermal, and system design.

LEDs Magazine: With Asian players dominating the mid-power space, how does Lumileds intend to compete in this arena?

Lesaicherre: Lumileds introduced its first mid-power product in early 2012, and in the subsequent 12 months, has expanded its mid-power family to include several products including one of the performance-leading products in the market, the Luxeon 3535L. We will continue to expand our mid-power product family and plan to introduce several additional products in the next few quarters.

As in high-power, Lumileds will win in mid-power by offering the highest efficacy products, by optimizing our LED products to specific lighting applications, and by aggressively reducing costs through scale and high volumes.

LEDs Magazine: Where does Lumileds see itself in 5 years?

Lesaicherre: We expect that the market will see significant growth in the adoption of LEDs in general lighting, in smartphones and other consumer devices, and in automotive applications. Indeed, LED penetration will be greater than 50% in several lighting segments such as streetlights and retrofit lamps, and double-digit growth will also continue in flash and automotive. The entire LED industry will be much larger than today, and Philips Lumileds will continue to be one of the leading global suppliers of LEDs.

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LightingEurope publishes research on LED-based human-centric lighting

Human-centric lighting, generally tunable solid-state lighting (SSL) that increases our comfort or wellbeing, can become a significant segment of the overall LED-based lighting market, according to LightingEurope. A joint study by LightingEurope, the German Electrical and Electronic Manufacturers' Association (ZVEI), and consulting firm A.T. Kearney projects human-centric lighting as a multibillion-Euro business that could hit EUR 1.4B (billion) in 2020.

Human-centric lighting can have a range of positive impacts on society, according to the new research and other studies on the topic. At its simplest, such lighting allows us to sleep and rest best, and perform with greater productivity during waking hours. Tunable lighting has also been shown to accelerate healing and help prevent chronic diseases. The study states that European industry is uniquely poised to capitalize on the opportunity in part because of a "solution-oriented understanding of customer requirements."

Human-centric lighting goes beyond the basic visual needs of people. Our populace is spending greater periods of time indoors and quality lighting is imperative for health. Technologies such as tunable color and white point take the concept further to enhance the daily lives of people. "Human-centric lighting solutions can actively support the circadian rhythm of human beings, thus promoting a person's wellbeing, mood, and health," said Alfred Wacker, chair of LightingEurope's Light and Health Working Group.

LEDs will become dominant source

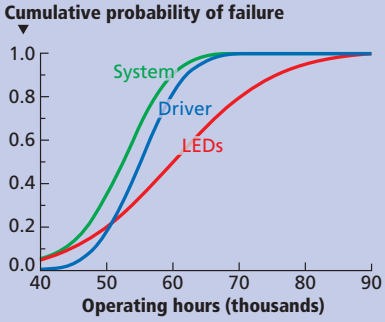
The new study notes that most human-centric lighting to date has been based on fluorescent sources, mainly because of the cost of LEDs. By 2020, however, LEDs will take over 90% of the human-centric lighting space, according to the researchers.

Indeed, LEDs enable many of the key elements of human-centric lighting. The new study says that lighting can meet our visual, biological, and emotional needs via control of direction of light, color temperature, and illuminance levels. LEDs are unique among light sources in enabling control in each of those dimensions. The Photon Project highlighted on page 9 is one example of researchers studying the link between lighting and wellbeing; » page 29

DOE publishes fact sheet on the lifetime and reliability of LED-based lighting

The SSL industry has come a long way in establishing standards for testing and rating both LED components and LED-based systems, although as the US Department of Energy (DOE) points out, there is still no definitive way to rate system life expectations. There are improved ways to test for and project lumen maintenance, but other failure mechanisms including driver life and system-level color maintenance remain hard to quantify.

The new DOE fact sheet on the topic, entitled "Lifetime and reliability," attempts to define all of the standards and projection methods that exist, and where the shortcomings exist in fully defining the characteristics of an SSL product at the system level. The main problems include the fact that existing methodology is primarily focused on lumen depreciation as the only failure mechanism, and there is no standardized methodology to rate elements that go into an SSL system beyond the light source.



The IES LM-80 standard provides definitive test methodology for white LED components. Most people discuss LM-80 relative to lumen depreciation and specification of time to L70 or 70% of initial flux output measured in thousands of hours. But LM-80 also defines component color maintenance and color shift. The IES TM-21 standard adds a way to project life » page 29

EPA publishes final Energy Star Lamps V1.0 specification

After having circulated a final draft back in July, the US Environmental Protection Agency (EPA) has now published the Energy Star Lamps V1.0 specification that will cover both LED-based retrofit lamps and legacy products such as compact fluorescent lamps (CFLs). Due to take effect on September 30, 2014, the final specification has minor additional changes and lamp manufacturers can immediately commission certification bodies (CBs) to begin testing products to the new specification. Indeed, the relatively lengthy certification process is the primary reason the effective date was set more than a year out.

The new lamps specification is a replacement for the prior independent Compact Fluorescent Lamps V4.3 and Integral LED Lamps V1.4 specifications. CBs will no longer certify products to the older specifications beginning May 30, 2014. On September 30, lamps certified to the prior standards will lose Energy Star status. There were comments from both individual companies and industry associations to the final draft. Those comments led to the final changes. Some of the changes include simplification of color-maintenance testing required on lamps within a product family, and a slight widening of the ambient temperature range covered in testing.

The changes also address some logistics issues. For instance, lamps will have to carry identifying information that allows matching the product to Energy Star listings after the packaging has been discarded. Dimming requirements also received a final tweaking with a clarification on measurements for noise and flicker.

The EPA also repeated its prior commitment to continuously study technology developments. The agency said it would look for opportunities for lower-cost A-lamps that could be good options for consumers in replacing incandescent lamps without a compromise in energy efficiency relative to lamps that meet the V1.0 requirements. ◄

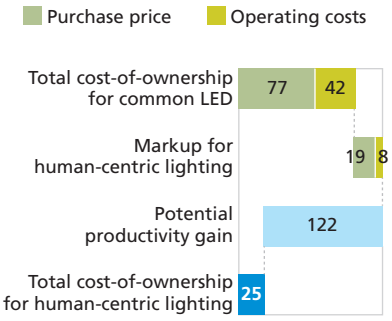
MORE: ledsmagazine.com/news/10/8/19

As the October 2013 *LEDs Magazine* went to press, the US government was in a shutdown mode due to ongoing disagreements between the executive and legislative branches. The EPA has temporarily shut down programs such as Energy Star and indeed cancelled the annual Partners Meeting that had been scheduled for October 7–9.

LightingEurope from page 27

it included an installation of the Philips Hue lamp in the Photon Pod at the London Design Festival.

The study justifies the optimistic viewpoint using case studies that detail a full financial analysis. In a factory application that is detailed in the nearby figure, a 25% upfront price premium and 20% greater power consumption of tunable lighting is offset by productivity gains.



The study is available on the LightingEurope website and includes projections for chronology of adoption and applications where human-centric lighting will be prominent, such as shopping, hospitality, health, education, office, industrial, and residential. The health sector will drive initial adoption but education is projected as the driver by 2020.

Assuming the technology takes off, it will make up 7% of the overall European lighting market by 2020. The strongest penetration could be in northern areas where days are short during the winter. ◄

LED reliability from page 27

beyond the 6000 hours of testing required by LM-80.

Today there is no way to test or project color maintenance at the system level. The DOE said that color shift has been less of an issue because it's more of an inconvenience as opposed to a safety issue whereas a drop in light output could be a safety issue. Still, lighting designers and specifiers would consider an unacceptable color shift as product failure.

Help is coming. The IES LM-84 standard will define methods for measuring both lumens and color maintenance at the lamp or luminaire level. Moreover, the TM-28 will prescribe methods to project lamp life based on LM-84 data. Later the IES may add projection methods for luminaires to TM-28.

The fact sheet does not offer a full solution for measuring and projecting lifetime or reliability. The report stated that with maturing LED and SSL technology, the issue may subside to some point but also noted "the products will continue to fail both catastrophically and parametrically, through various mechanisms."

The DOE also mentioned the possibility that the industry may be better off with products rated for shorter lifetime such as 10–15 years rather than say 30 years, because lighting is often remodeled on a shorter cycle. We covered similar ground in a recent editorial (leds magazine.com/features/10/7/3). The DOE did add that shorter life impacts sustainability because more waste material is generated.

One thing that the fact sheet does not address is how lifetime and reliability are impacted in products that use a mix of colored LEDs, or a technology such as remote phosphor that relies on royal blue LEDs, often referred to as blue pumps. The existing standards such as LM-80 only define test methods for phosphor-converted white LEDs, or modules that use remote phosphor or color LEDs. But other system architectures are becoming popular in some applications. ◄

SIL Europe fosters communication amongst technology innovators and financiers

The full-day Investor Forum at the 2013 Strategies in Light Europe event is just one of the opportunities that should inspire collaboration between financial entities, solid-state lighting companies, and startups to keep this high-growth industry moving, reports **KATYA EVSTRATYEVA**.

Innovative technologies create new products, companies, jobs, and even industries. LEDs are not an exception, and lighting is now the dominant application for LEDs, surpassing the mobile appliances market sector, according to Strategies Unlimited's global LED market analysis for 2013. The LED luminaire market in particular is forecasted to grow to $16.6 billion by 2016, according to our research. Several conditions, including improvements in performance and price of commercially available high-brightness LED packages, heightened concerns regarding energy efficiency, and the phase-out of incandescent bulbs, have combined to further the case for adoption of LED technologies in lighting applications.

In the past decade a number of solid-state lighting (SSL) startup companies have come to market as university spin-offs or as garage ventures and became internationally recognized brands. The availability of funding at every stage is critical for a company's successful growth, and Strategies in Light Europe (November 19–21, 2013, in Munich, Germany) recognizes the need to foster an ecosystem that will provide a platform for communication among financial entities and companies.

For the third consecutive year, SIL Europe will offer an Investor Forum, a full-day event that will provide presentations and discussions of investment opportunities in the SSL industry. The Investor Forum is organized by Strategies Unlimited, a research unit of PennWell Corporation, in collaboration with Berenberg Bank.

KATYA EVSTRATYEVA *is an analyst at Strategies Unlimited, a PennWell Corporation subsidiary, and co-chair, Strategies in Light Europe.*

PROGRAM: Solid State Lighting Investor Forum

The SSL Investor Forum is specifically designed for current and potential investors, as well as LED and LED lighting companies seeking financing opportunities. The Forum will provide valuable information and excellent networking opportunities.

8:00–8:15 am
Strategies Unlimited, Katya Evstratyeva, Market Research Analyst, USA

8:15–8:45 am
Berenberg Bank, William Mackie, Equity Research, Capital Goods & Industrial Engineering, UK

8:45–9:15 am
Philips, Jens Milnikel, Head of Strategy, Lighting, Netherlands

9:15–9:45 am
OSRAM Licht AG, Boris Tramm, Head of Investor Relations, Germany

9:45–10:15 am
Cree, Stephen Greiner, Vice President, EMEA, USA (subject to change)

10:15–10:45 am
Delegate Coffee Break

The program for the event will include market overviews of the global and European LED lighting industries provided by Strategies Unlimited analysts and Berenberg Bank, followed by presentations from public companies including Philips Lighting, Osram AG, Cree, Zumtobel, and Dialight.

The SIL Europe program will provide presentations from established non-public manufacturers of LED lighting products, such as Xicato, Digital Lumens, and Soraa, as well as presentations from startup companies that provide new solutions in LED technology and applications — look for sessions from Nanotherm, Carbodeon, MLED, InfiniLED, LUXeXcel, and Cooledge.

A presentation from design firm BillingsJackson (UK), known for its work in luminaire design as well as complex architectural commissions, will shine a light on global projects in which LED technology plays a central role. The program will conclude with a panel discussing the challenges, opportunities, and prospects for innovations and investments in the SSL ecosystem. At press time, the confirmed participants for the panel are William Mackie, head of equity research at Berenberg Bank (UK); Jens Milnikel, head of strategy at Philips Lighting (Netherlands); Tom Pincince, CEO of Digital Lumens (USA); and a partner from Generation Investment Management LLP (UK).

The Investor Forum at Strategies in Light Europe will take place on November 19, the day preceding the main conference sessions. See the full listing of Investor Forum presenters below. Further information about the Forum or the complete conference may be found at sileurope.com.

10:45–11:15 am
Zumtobel AG, Harald Albrecht, Vice President, Corporate Controlling & Investor Relations, Austria

11:15–11:45 am
Dialight PLC, Mark Fryer, Group Finance Director, UK

11:45 am–12:15 pm
Xicato, Menko Deroos, Chief Executive Officer, USA

12:15–1:00 pm
Delegate Lunch

1:00–1:20 pm
Cambridge Nanotherm Ltd./Enso Ventures, Kirill Mudryy, Director, Cambridge Nanotherm Limited, UK

1:20–1:40 pm
mLED Ltd., Seonaidh MacDonald, Chief Executive Officer & Board Director, UK

1:40–2:00 pm
InfiniLED, Joe O'Keefe, Chief Executive

Officer, Ireland

2:00–2:20 pm
Carbodeon Ltd. Oy, Asko Vehanen, Chief

Executive Officer, Finland

2:20–2:40 pm

Delegate Coffee Break

2:40–3:00 pm
Digital Lumens, Tom Pincince, President

and Chief Executive Officer, USA

3:00–3:20 pm
LUXeXcel, Richard van de Vrie, Chief Executive Officer, Netherlands

3:20–3:40 pm
Cooledge, Uwe Hock, Sr. European Business Development, Canada

3:40–4:00 pm
Billings Jackson Design, Eoin Billings, Founding Director, UK

4:00–4:20 pm
Soraa, Nick Farraway, Senior Vice President, UK

4:20–5:00 pm
Panel Discussion
Moderator: Katya Evstratyeva, Analyst, Strategies Unlimited
Panel: Will Mackie, Head of Equity Research, Berenberg Bank; Jens Milnikel, Head of Strategy, Philips Lighting; Tom Pincince, Chief Executive Officer, Digital Lumens; Partner, Generation Investment Management LLP

For information on the Technology and Market Tracks, see additional Strategies in Light Europe conference previews contributed by Bob Steele (ledsmagazine.com/features/10/9/11 and ledsmagazine.com/features/10/8/3, respectively).

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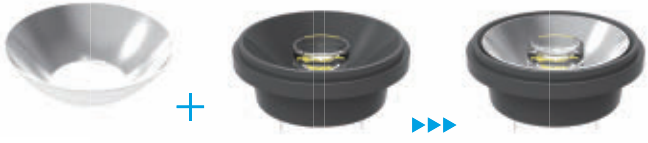

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High uniformity collimated system -Patent pending

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Birmingham celebrates railroad history, connects city center with LEDs

MAURY WRIGHT explores how a renowned light sculptor used dynamic LED lighting to connect a new urban park with the city center in Birmingham, Alabama, and to simultaneously celebrate the historic role the railroad played in the city's history.

Most major industrial cities in the US are situated on navigable bodies of water, points out Atticus Rominger, chief public and investor relations officer at the REV Birmingham organization charged with revitalizing the Birmingham, Alabama downtown area and neighborhoods. For Birmingham, it was the major railway line that split the city — running predominantly east and west — and enabled the city to become a 20th-century industrial and transportation center and a leader in iron and steel manufacturing. While much of the heavy industry is gone, Birmingham has chosen to celebrate its history as a major railway hub and has built a spectacular urban park and minor-league baseball stadium called Regions Field on the south side of the tracks. Now an LED light sculpture by Bill FitzGibbons called LightRails has turned the city's 18th Street railway underpass into a dynamic interconnect between the revitalized south side and city center to the north (Fig. 1).

Like many cities caught in a transition away from heavy industry, Birmingham has been through a period where many of its residents avoided the downtown and other downtrodden areas. Over the course of the past few decades, the city has strived to encourage development downtown; indeed, the city center area has attracted restaurants and entertainment venues along with increased occupancy in office space.

The south side of the tracks, however, has fared more poorly. Rominger said that the railway underpasses, while lit with functional white light, had become home to vagrants and that residents or visitors were hesitant to walk through the pedestrian passages located adjacent to roadway tunnels.

Still, Rominger said, "Rather than hide it, Birmingham decided to highlight the railroads," given the important role the lines played in the city's history. Moreover, in the downtown area the four underpasses were constructed in the 1930s with Art Deco style. In 2010, the city opened the new urban park called Railroad Park that lies parallel to the tracks between 14th and 18th Streets, across the railroad from city center. The park includes nine acres of open lawn along with lakes and recreational facilities, and serves as a concert and entertainment venue.

Connecting the districts

Despite the popularity of the park and the presence of state-of-the-art security, there was still little movement of visitors between the park and nearby city center. Soon, however, the baseball stadium would add to the story. The city had planned to open Regions Field across from the southwest corner of Railroad Park in April 2013. Rominger said that REV Birmingham and the city realized in mid-2012 that it needed to better connect the park and baseball district with city center.

And in spite of the fact that the city has

FIG. 1. The LightRails project in the 18th Street railroad underpass includes a roadway and a pedestrian walkway that connect the parks district to city center. (All photos, Bill FitzGibbons)

had financial struggles at times, there is a local organization called the Community Foundation of Greater Birmingham that establishes Community Catalyst Funds allowing local philanthropists to donate money to help drive transformational change in the city. Funds from that source allowed REV Birmingham to move relatively quickly on what was an expensive proposition up front — installing color-changing LEDs and a control system.

Through contacts with the local arts district, REV Birmingham met light sculptor Bill FitzGibbons, who had previously used color LED lighting under freeway underpasses in his hometown of San Antonio, Texas. REV Birmingham first discussed the project with Fitzgibbons in November 2012, yet he wouldn't visit the site until March 2013. But REV Birmingham wanted the project lit during the 2013 baseball season. Rominger said the philosophy was "Let's not walk, let's run," speaking for the project backers.

Opportunities and obstacles

When FitzGibbons saw the project site, he immediate recognized the potential for the light sculpture based on the architectural style — especially in the pedestrian walkways that included beams and arches (Fig. 2). FitzGibbons said, "If I were to design an underpass for an LED art installation, this is the type of design I would implement."

The desired schedule of course was a problem. But FitzGibbons had prior experience using Philips Color Kinetics color-tunable luminaires and controllers in such projects, and the company had the required products available with relatively short lead times or from stock.

In many municipal projects, multiple levels of government can also delay projects. In Birmingham, the city was behind the project. The railroads own the bridges, but the city is charged with maintenance and FitzGibbons said the railroads took a hands-off approach to the project. So LightRails progressed much more quickly than many projects.

Electrical service was also a non-issue in the LightRails project. The city had installed new white lighting in the underpasses within the past decade. While the lighting itself had not been well maintained, the electrical service was more than sufficient to power the new lighting. FitzGibbons said that his team had to install a new NEMA box to house the lighting controller and run some new conduit and wiring to the fixture locations.

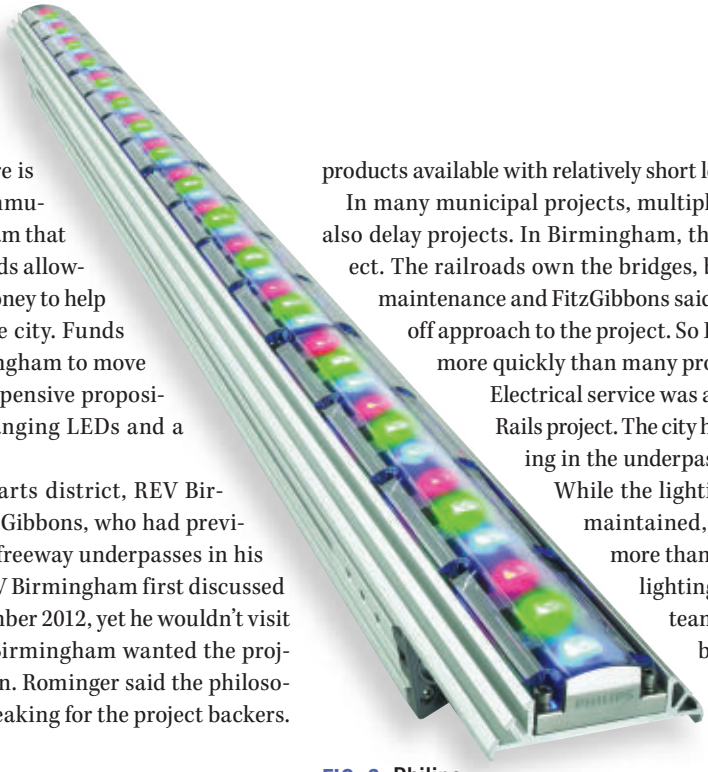

FIG. 3. Philips Color Kinetics ColorGraze MX Powercore luminaires graze surfaces and were one of three RGB fixtures used in the project.

RGB fixtures and controller

Ultimately, FitzGibbons specified around 100 luminaires for the project including a mix of ColorGraze MX Powercore (Fig. 3), ColorBlast Powercore, and ColorBurst Compact Powercore fixtures. All of the products are based on red, green, and blue (RGB) LEDs. A Philips Color Kinetics iPlayer3 Controller

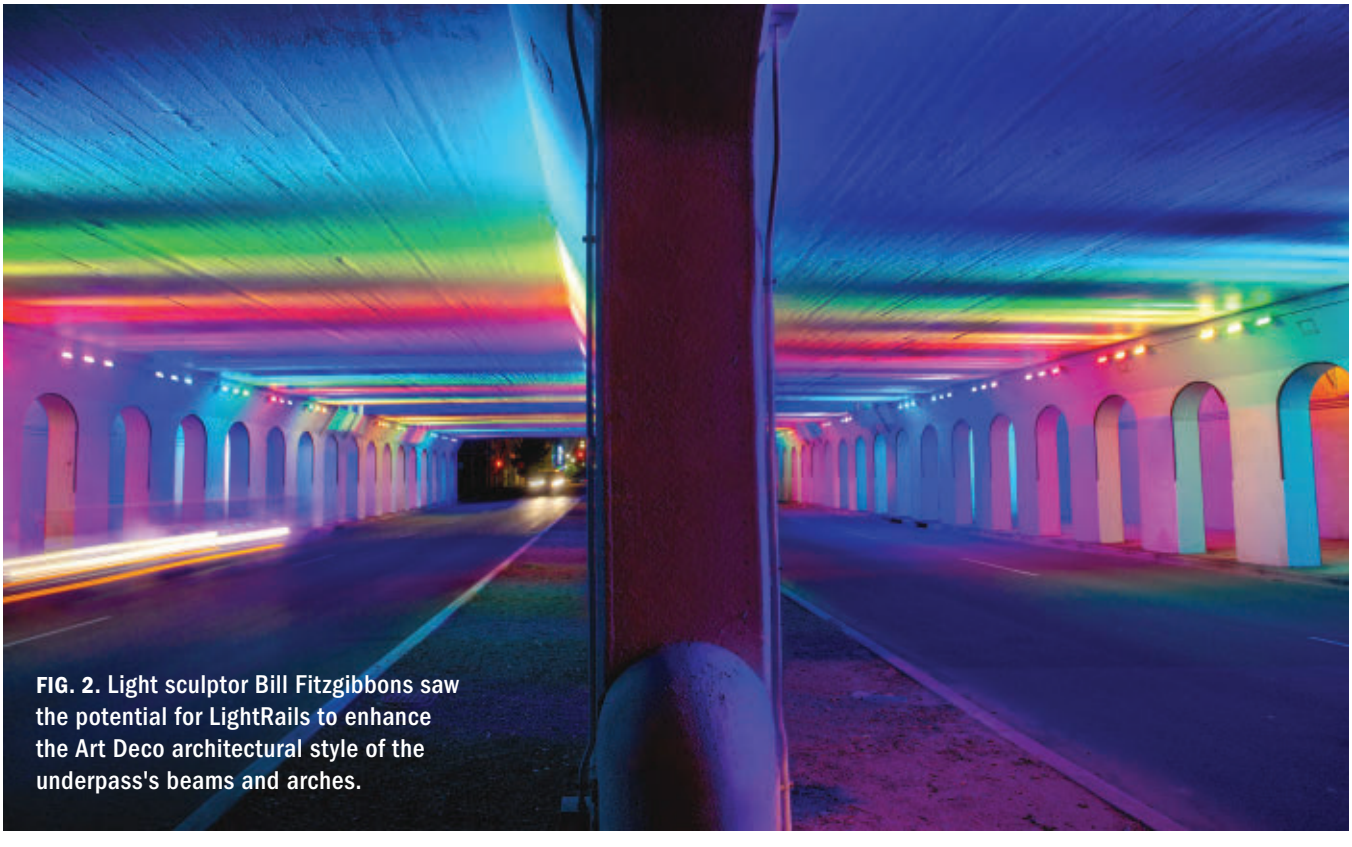

FIG. 2. Light sculptor Bill Fitzgibbons saw the potential for LightRails to enhance the Art Deco architectural style of the underpass's beams and arches.

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links to all of the fixtures. Jeff Campbell, product manager at Philips Color Kinetics, said that the installation uses four-conductor cables that distribute both power and control signals to the luminaires using a DMX network.

The design uses linear 2- and 4-ft ColorGraze fixtures to graze the surfaces. The rectangular ColorBlast fixtures are used for wall washing and floodlighting. And the smaller round ColorBurst Compact fixtures add accent lighting. All work in concert to provide effects ranging from static color spectra to dynamic changing colors and effects.

FitzGibbons programmed the system to play a 17-minute program that loops each night from dusk to dawn. The installation provides the requisite level of white light during the day. FitzGibbons described some of the effects as using colors with white sparkles and using "color as a column to explore the architectural space." Especially in the smaller pedestrian tunnel, a single fixture can generate a reflection 360° around the tunnel. FitzGibbons added that in the pedestrian tunnel, "The beams and arches provide additional opportunities to show the spectrum."

The installation also provides the opportunity for special shows. For example, FitzGibbons said he has already programmed the iPlayer3 to switch automatically to a holiday presentation in December with an emphasis on red and green colors. Philips' Campbell said that the controller could store even more programs that can be triggered by an astronomical clock. New programs can be downloaded via an SD card.

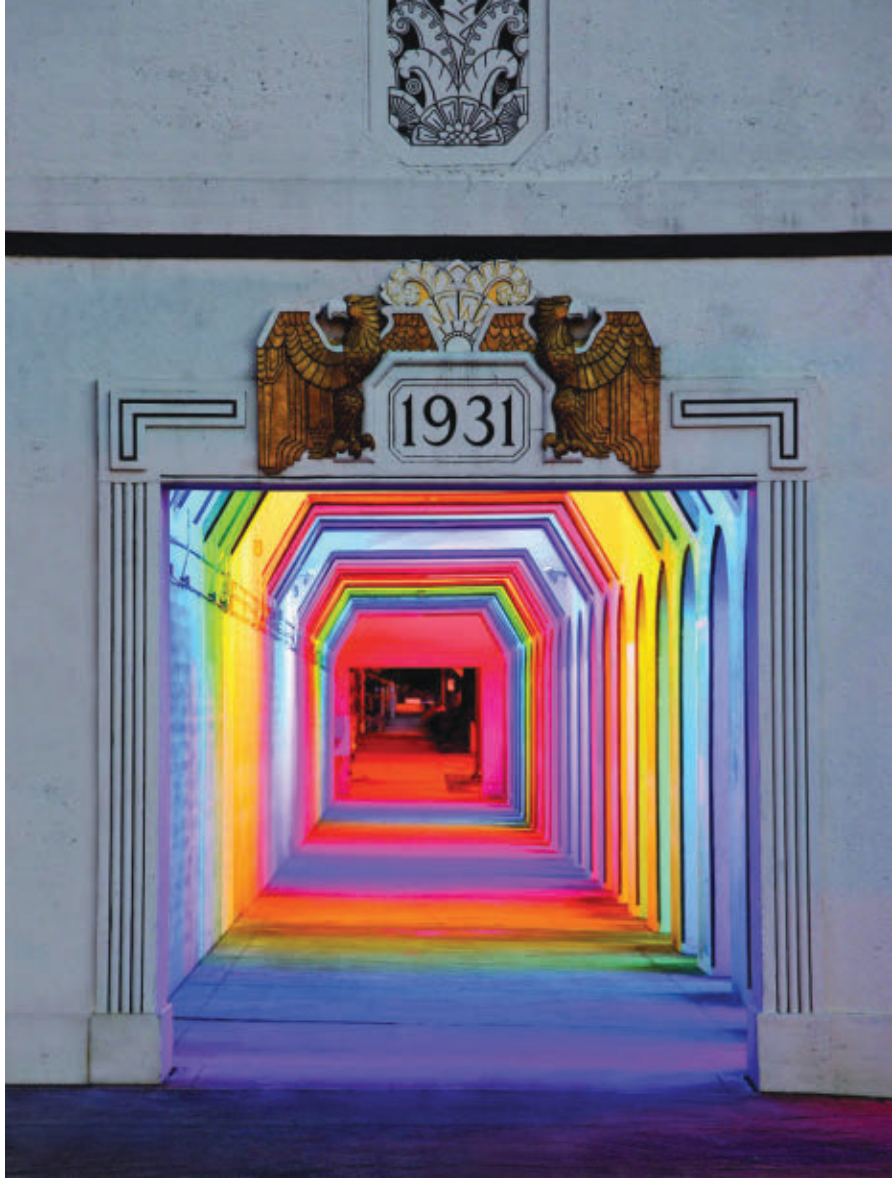

FIG. 4. The underpass architecture and fixture placement create dynamic columns of light spectra that explore the architecture.

June LightRails debut

Despite the compressed schedule, Birmingham and FitzGibbons lit the LightRails project on June 27, 2013, allowing baseball fans and park users to make a safe and enjoyable walk between what is being called the parks district and city center (Fig. 4).

But LightRails has done far more. Rominger said the situation has changed from one of "trying to get people to walk through the underpass" to one where "people come downtown just to see the lights." FitzGibbons isn't surprised and added, "It's the power of what contemporary light sculpture can do." An uninviting underpass has become a place people want to visit. About such public projects, FitzGibbons said, "They are transformative for urban areas."

Not only has LightRails brought visitors to the downtown area, it has helped the city mitigate some of its vagrancy issues. With more people in the area and the improved lighting, the vagrants quickly disappeared from the area.

Operational costs and light spill

While LightRails has been a clear success early on, we wondered about potential ongoing concerns about excessive use of electricity or light pollution. About the electrical cost, FitzGibbons said that the color lighting installation was designed to use one third of the energy of the prior white lights. Rominger said the city hasn't measured energy usage as yet, but he doesn't foresee a problem given that the project uses efficient LED sources. Philips Campbell added that 30W to 50W Color Kinetics fixtures regularly replace 100W white lights that use legacy sources.

As for light spill, the LEDs also are directional and mainly focused on surfaces in the tunnel. The installation neither spills light nor distracts drivers, according to Rominger and FitzGibbons. Rominger said, "We have not had a single comment about it that was negative."

Birmingham is now looking for funds and ideas for the three other underpasses in the immediate area of Railroad Park. Regions Field was a blockbuster success in its first baseball season with an architecture modeled after the historic Sloss Furnaces company from Birmingham's past. LEDs and LightRails have added to the momentum building in the downtown area, and demonstrate the benefits of LED-based public art.

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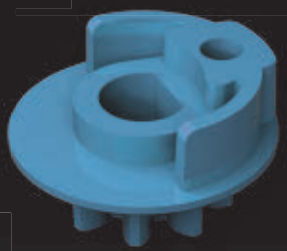

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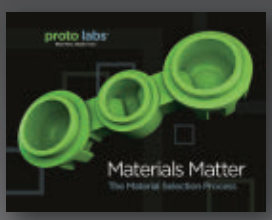

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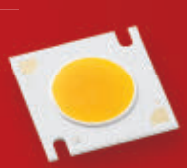

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LEDs ready to displace halogen in MR16 lamps

Despite the small size, thermal challenges, and high-CRI requirements of LED MR16 retrofit lamps, **MARK YOUMANS** and **MARK McCLEAR** write that it is now "game over" for the halogen incumbents.

Halogen PAR and MR integral lamps have been a mainstay for the retail and residential lighting markets for decades. These lamp sources have excellent color rendering and narrow light distribution capabilities but also exhibit relatively short service lifetimes and poor energy efficiency. The latter two weaknesses have been exploited effectively by many successful solid-state lighting (SSL) retrofit lamp products, but until recently the LED technology had not yet advanced enough to simultaneously achieve the high efficacy, long lifetime, focused light distribution, and high color rendering index (CRI) required to truly match the performance of these traditional light sources. The latest LEDs, however, promise to supplant halogen in new SSL designs as we will demonstrate in comparing some reference designs and existing LED and halogen products.

The MR16/GU10 lamp poses perhaps one of the biggest challenges to LED retrofit design. In addition to the stringent requirements mentioned previously, the MR16 lamp is an extremely small size and has relatively little available surface area to dissipate the high power densities required in the application. This article will discuss recent breakthroughs in LED lamp architecture that enable all of these problems to be solved simultaneously.

MARK YOUMANS *is an applications engineer at Cree, Inc., and* MARK McCLEAR *is vice president of applications engineering at Cree, Inc.*

CRI: The last problem to solve

The most common halogen MR16/GU10 lamps on the market are the 20W, 35W, and 50W varieties. Fig. 1 shows examples of some of the styles of LED retrofit lamps that have successfully met or exceeded the luminous flux, Center Beam Candle Power (CBCP), efficiency, and lifetime requirements of these common lamp types.

FIG. 1. 25W- and 50W-equivalent LED MR16 lamps.

Different numbers, configurations, and models of packaged LEDs were used to achieve these results, but each of them — like nearly 100% of the commercially available LED retrofit lamps currently on the market — was only able to achieve a CRI of around 80. While 80 CRI is normally acceptable for many residential applications, retail applications often demand CRI in excess of 90 to help accentuate the color and quality of fabrics, skin tone, and food items, and this is where many of these early LED retrofit lamps have so far fallen short of the mark.

The technology to produce LED lamps with 90 CRI or greater has existed for several years but the efficacy penalty — generally around 20% — of going from 80 to 90 CRI or beyond has been too much to pay in terms of cost, but just as important is thermal load in this thermally constrained MR16/GU10 application.

Alternative solutions

To demonstrate that the color/CRI challenges are now achievable, Cree application engineers used 90+ CRI versions of a new Generation 2 series of high-efficacy Cree XLamp LEDs to build working MR16 reference designs. The XM-L2, MK-R2 and MT-G2 depicted on page 40 were used to create 20W-, 35W- and 50W-halogen-equivalent MR16 lamps. The photo on page 42 shows one of the reference lamps. The three designs use LED components assembled onto off-the-shelf heat sinks along with off-the-shelf optics and drivers. These new reference designs of high-CRI MR16s are all around 50–55 lm/W as assembled, and all three designs hit or exceed their 20W, 35W, and 50W equivalent targets. With further optimization of the drivers, optics, and heat sink, even higher equivalencies are possible from these LEDs.

The three XLamp reference designs discussed here are not the first or only LEDs on the market to take on the difficult MR16

design problem. Simultaneously attaining high CRI and all the other aforementioned performance constraints in an MR16 format has also recently been achieved by using so-called gallium-nitride-on-gallium-nitride (GaN-on-GaN) LED technology. GaN-on-GaN LED technology, because of the homogenous substrate or wafer, allows for relatively higher drive currents and therefore higher current densities with much reduced efficacy droop. A comparison of the major performance parameters of the two solutions is summarized in the table.

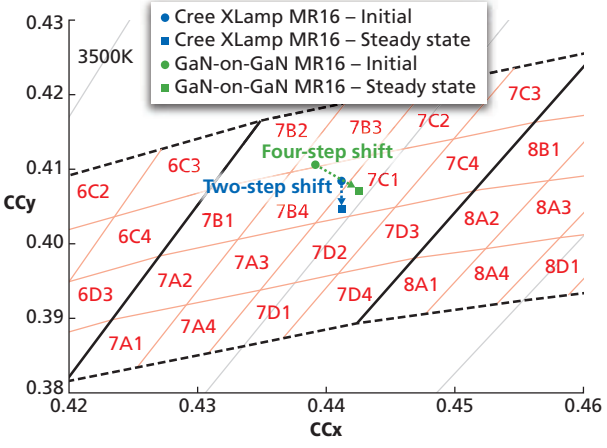

FIG. 2. Cree XLamp LED and GaN-on-GaN LED color shift over temperature.

Heat, color stability, lifetime

All LED lamps — regardless of chip architecture or substrate technology — represent a complex and highly engineered system. These systems consist of the LED chip, the phosphor down-converter, and the encapsulant and packaging materials. As mentioned, GaN-on-GaN LED chip technology affords the opportunity for higher drive currents and higher current densities, with improved efficacy droop capabilities. Even though the GaN-on-GaN chips may perform well under these stressful conditions, the phosphor system and the LED package still have to reliably survive these conditions or the MR16 lamp cannot maintain the performance of halogen lamps over time.

The phosphor conversion efficiency of any LED lamp system can degrade significantly vs. increased operating temperature. This means that as the LED lamp heats up, the color output changes until it reaches a steady thermal state. The phosphor response of the Cree and GaN-on-GaN LED MR16 solutions over temperature is shown in Fig. 2.

Both the magnitude and the direction of the color shift are important since a horizontal shift in color is likely to be perceived by the observer as a change in CCT (about 100K in this case), whereas a vertical shift in color runs more or less along iso-CCT lines (about 30K here).

At 3000K, the ability of the human visual system to perceive variation in CCT is about ±50K, according to recognized color science experts Wyszecki and Stiles. Therefore, the difference in color from initial startup until steady state would likely be noticeable for the system that shifts horizontally.

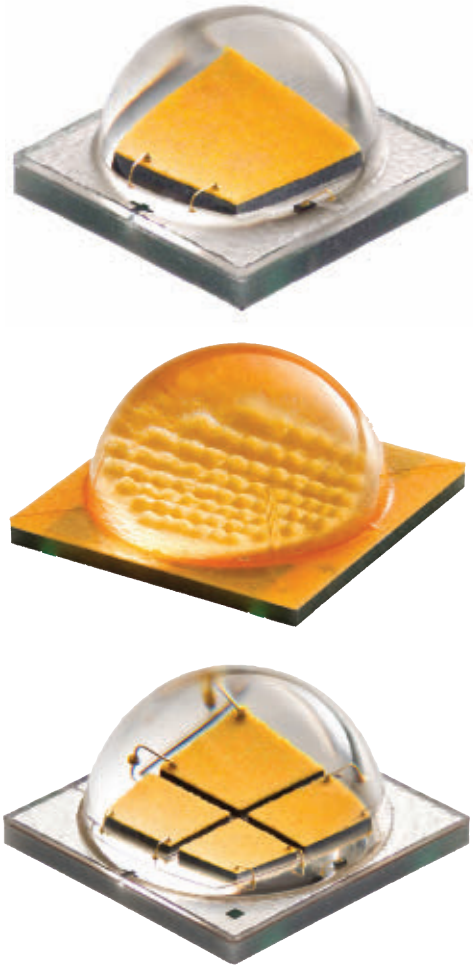

FIG. 4. Generation 2 XLamp LED lamps: XM-L2, MK-R2, and MT-G2.

Temperature can also impact CRI. Fig. 3 shows two spectral power distribution plots, each normalized to their peak intensity. A change in shape of these curves as a function of temperature can indicate a change in color rendering between the initial startup conditions — normally the data sheet

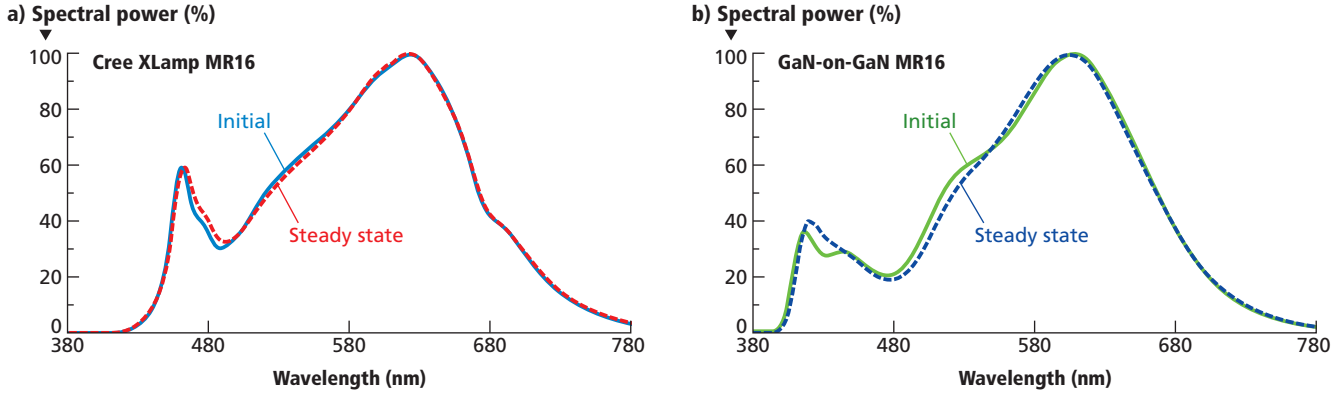

FIG. 3. a) Cree XLamp LED spectral power distribution (SPD); b) GaN-on-GaN LED SPD.

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conditions — and the thermally stable steady state of the installed MR16 lamp.

Packaging materials

High operating temperatures and high drive current densities can also affect the encapsulant and packaging systems of LED lamps. Driving LED lamps at higher power density can lead to package depreciation, even if the chip itself may be stable. There is a range of silicone encapsulants used in the LED industry, and those details are beyond our scope here, but we can discuss the general impact of temperature and materials.

These silicone encapsulant materials typically are polyorganosiloxanes, also called siloxanes. Cree has published a chemical compatibility application note that goes into greater detail on the topic (www.cree.com/products/pdf/XLamp_Chemical_Comp.pdf). At elevated temperatures, volatile hydrocarbons can diffuse through the silicone. With the high temperatures and high amount of radiant energy present, these impurities can darken over time and cause light degradation. Thus, the higher the drive current, the more light being emitted from the chip and the faster the lumen depreciation of the lamp.

The three XLamp LED components used in this work have gone through rigorous, long-term lifetime testing, as defined by the Illuminating Engineering Society (IES) LM-80-2008 long-term test configurations. Based on available LM-80 data, and using the IES TM-21-2011 method to project, all the XLamp LEDs used in the High-CRI MR16 reference design show an L70 value of greater than 36,000 hours at the drive current and operating conditions of the respective three MR16 reference designs. Remember these lifetime figures are projections and not warrantied specifications.

Halogen MR16 B50 lifetimes range between

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Performance comparison of halogen, Cree Generation 2 LED, and GaN-on-GaN LED MR16 retrofit lamps.

Source	Lamp power (W)	Luminous flux (lm)	Efficacy (lm/W)	CRI	CBCP (cd)	Beam angle (°)	Energy Star equiv. (W)	Color shift with temp.	Projected lifetime (hr)
20W Halogen MR16	20.0	200	10.0	100	1000	24	20	NA	B50: 3,000
35W Halogen MR16	35.0	540	15.0	100	1750	24	35	NA	B50: 3,000
50W Halogen MR16	50.0	790	16.0	100	2500	24	50	NA	B50: 3,000
Cree XM-L2 MR16	4.5	249	55.7	92	1037	23	20	Two-step	L70: >36,300*
Cree MK-R MR16	8.1	406	50.1	91	2287	22	40	Two-step	L70: >36,300*
Cree MT-G2 MR16	11.3	560	49.5	91	2379	25	50	Two-step	L70: >36,300*
GaN-on-GaN MR16	11.5	360	28.7	95	1980	22	35	Four-step	N/A
GaN-on-GaN MR16 v2	11.9	412	39.2	95	2310	22	40	Four-step	N/A

*Projected lifetime, not a warranty or specification; warranty available at www.cree.com

FIG. 5. XLamp MT-G2 MR16 50W-equivalent reference design.

2,000 and 10,000 hours, and most commercially available halogens typically have rated lifetime of 3,000 hours. The LM-80 data for the GaN-on-GaN LED described here has not been published, but Cree has tested some of these MR16 lamps in real-world scenarios (open air, Ta = 22°C; closed fixtures, Ta = 55°C) and found that the L70 for at least a small sample of these MR16 lamps can be as short as about 4,000 hours — barely exceeding typical halogen rated lifetimes.

Fig. 6 shows a graphical comparison of a Cree XLamp LED component with regard to two commercially available GaN-on-GaN LED MR16 lamps under two different ambient operating conditions, and also the halogen MR16 B50 rated lifetime. From this we can see the degradation effects the very high operating temperatures and current densities have on the phosphor and packaging elements of the LED lamp.

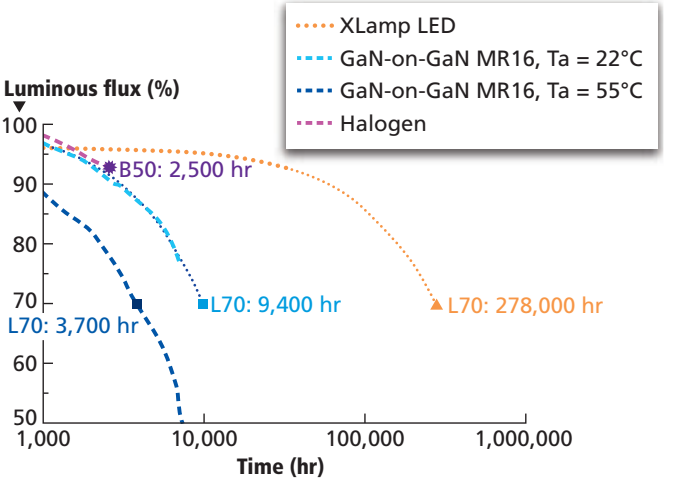

FIG. 6. L70 comparison of Cree TM-21 data to other commercially available lamps.

UV light content

One final point of note with LED MR16 lamps involves applications that are sensitive to ultraviolet (UV) light. Some lighting applications involving fabrics, paints, and sensitive artwork have had problems over the years with the UV content of halogen lamps. To compensate for this, halogen MR16 lamps are sometimes fitted with UV (also sometimes infrared, or IR) filters.

One potential drawback of this GaN-on-GaN technology is the use of shorter-wavelength UV light (less than 400 nm) which, like the UV content of halogen MR16 lamps, has the potential to cause photo-degradation and may require UV filtering in some sensitive applications. Cree XLamp LEDs are based on a blue (nominally 460 nm) LED chip, which is generally thought to have much less potential for such photo-degradation than the sub-400-nm UV light content in the other two light sources.

Current LED technology has progressed to the point where all the performance metrics of halogen lamps — including rated lifetime, LPW efficacy, color temperature, color stability, CBCP, and now CRI — can be met or exceeded. This work looked at the most challenging halogen application — the MR16/GU10 lamp — but the findings can be generalized to larger halogen lamp styles like PAR20, PAR30, PAR38, and AR111 as well. These performance metrics were met both with a new generation of traditional blue LEDs as well as GaN-on-GaN LEDs. But care must be taken in the end application to minimize operating temperatures, which will ensure the rated lifetime and color stability. Moreover, designers must guard against UV-induced damage in sensitive applications for the GaN-on-GaN-based LED products evaluated here.

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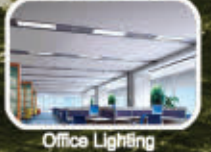
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Energy efficiency may come at the cost of consumer confidence

As the European Union's EcoDesign Regulation requirements continue to escalate, **CAROLINE HAYES** reports that LED replacements for mains-voltage halogens may not deliver on consumer expectations on time, while directional SSL lamps are moving faster than the pace of the scheduled phase-out.

Although the initial deadline for the first phase of the European Union (EU) EcoDesign Regulation has passed (September 1, 2013), there is still a lot of debate and contention around the initiative to replace various halogen lamps with LED lighting. Specifically, LightingEurope believes that no LED-based lamps will meet the Stage 6 requirements of European Commission (EC) Regulation 244/2009. In other cases, proponents of a faster transition to energy-saving solid-state lighting (SSL) believe that the EU should have mandated a faster transition — for instance, in directional products such as MR16 lamps.

EU Regulation 244/2009 sets minimum performance requirements (minimum lamp efficacy and lumen equivalency with incandescent lamps) for non-directional light sources, including LED lamps. Other EcoDesign Regulations such as EU 1194/2012 cover directional LED lamps, LED modules, and LED control gear, and still other EcoDesign Regulations cover efficiency in products well beyond the lighting space.

LightingEurope, the association representing lighting manufacturers and national lighting associations, has asked for a rethink on the timing of Stage 6 of 244/2009. That stage, among other things, will address non-directional, screw-based lamps and essentially phase out halogen lamps as an option. LightingEurope advocates that 2019 is a more realistic date for halogen bulbs to be replaced, rather than the current deadline of 2016. There are several reasons for this request: affordability, a desire for consumer choice, and quality issues.

CAROLINE HAYES *is a contributing editor with LEDs Magazine.*

Subject under typical 80 CRI blue-pump two-phosphor LED with truncated spectrum (left), compared with subject under 95 CRI/95 R9 Soraa violet-pump, three-phosphor GaN-on-GaN LED with full visible spectrum (right).

Jürgen Sturm, secretary general of LightingEurope, is concerned that an accepted technology is taken away with no viable alternative offered. "It is not the technology, more the LED market maturity," he said. A mains voltage halogen bulb today costs around €1.00–€1.50 ($1.30–$2.00), whereas depending on the application and the country of purchase, a replacement LED can cost €15.00–€20.00 ($20.00–$27.00), he estimates. There has to be consumer choice, he argues, and 2016 is too soon for the market to be able to lower costs. Instead, he believes 2019 may be the right time for high-quality LEDs to be available to consumers at the right price point.

Peter Hunt, CEO of the UK's Lighting Industry Association (LIA), adds, "One of the reasons that LightingEurope is in favor of delaying the effective ban on halogen is the potential impact on jobs within the EU, in addition to the likelihood that quantities and quality, plus affordability, won't be available in 2016." He balances the panic of the 2016 deadline with the details of the EU bureaucracy, saying that it provides for a revision to ensure that the technology is on track to deliver the amount and quality of affordable lamps to replace those removed from the market.

Consultation and surveillance

The LIA understands that the Commission

is likely to engage a consultant to make a market assessment, possibly in consultation with stakeholders. This is also likely, it says, to require confirmation by member states following a Regulatory Committee vote.

Georg Steinberger of Avnet advocates a technically sound and fair decision across countries.

Another concern of LightingEurope is that the EcoDesign Regulation was introduced without industry consultation. The fear is that halogen bulbs will be phased out before the market is mature, leaving low-quality LEDs to be seen as the only option, based on prices. This will be detrimental to the maturing market, Sturm warns.

The same issue, he reasons, could damage market credibility. If the 2016 deadline does not allow producers to deliver quality products at an acceptable price, consumers may not have any option but to buy LED bulbs based on price when choosing a product from the store shelves. This could damage the consumers' image of what is "the most energy-efficient light source invented," says Sturm, "but the guiding principal must be consumer choice."

A related issue is that there is no provision for what Sturm calls "market surveillance." Each EU member state is to be responsible for policing the pricing and quality of LED replacements. What is affordable in Sweden may be unacceptable in Romania, for example, he points out. The lack of market surveillance in member states is a particular worry for LightingEurope.

Nick Farraway, international sales manager at Soraa, agrees that the EU has fallen short by making each member state responsible for implementing the Regulation. "Some countries are better than others; some will take reasonable steps to check retailers' shelves, but others muddle the issue," he argues. While large producers will protect their brands, there will be many products imported without quality controls and sold alongside the expensively produced ones.

Nick Farraway of Soraa suggests that lax legislation will dilute lighting quality.

"While some companies will follow the Regulation, there will be no checking or action if others do not," Farraway warns. This not only creates an unfairness in the market but could do harm as consumers, buying cheaper brands, are left with a poor impression of LED lighting. He argues that consumers may not see that replacing a halogen mains or low-voltage bulb that achieves an efficiency of 9–17 lm/W with an LED bulb of 50–60 lm/W is an energy-efficient option when the cost can be six times that of a halogen bulb. For hotels and commercial installations, the payback period should be 6–12 months, but for homes, where lights are used less, the payback may be extended to a period of 3–4 years, which is not such an obvious financial return for consumers.

EcoDesign deficiencies

For Farraway, there are other flaws in the EcoDesign Regulations. One is that the low specified CRI (color rendering index) may deter end users from LED lamps. Halogen lamps are popular with consumers because they render color well, he says, enhancing interiors. He is concerned that the EU is allowing quality to be diluted. He fears lessons have not been learned from the introduction of energy-efficient compact fluorescent bulbs. "Compact fluorescent is a good technology to save money, but is a poor light, and therefore unpopular," he says, referring to its green hue. He wants a much more stringent color metric for replacement bulbs. The EU wants 80 CRI, but Farraway wants 95 CRI or greater, although he concedes that the obstacle to this is a more difficult and more costly process technology.

Typical LED manufacturing lines today use gallium nitride (GaN) on sapphire substrates and, to a lesser extent, the newer GaN on silicon carbide. These can be seen as the "incumbent" LED materials, alleges Farraway, who advocates Soraa's GaN on GaN as an emerging technology that is "infinitely superior." Soraa also employs a violet LED outside the visual spectrum and a mix of three phosphors to deliver better color whereas most white LEDs mix blue light from an LED and one or two phosphors (see photo on page 45).

"Reaching high R9 values — which factor heavily in good color rendering for skin, food, natural materials — in non-native (i.e., non-GaN) substrates and other technologies has traditionally been difficult because of efficiency limitations," Farraway said. "What GaN on GaN does is to enable better efficiencies and higher current throughput." In the spirit of fairness, Farraway noted that Seoul Semiconductor and Mitsubishi's Verbatim are also developing GaN-on-GaN processes.

Jürgen Sturm of LightingEurope advocates consumer choice.

Another criticism from Farraway is the reverse of that from LightingEurope: He criticizes the slow phase-in of regulations on directional lamps such as MR16 halogen products, which won't happen until 2014 and 2015. Incumbent players, like Philips, Osram, and GE, have large factories and employ many people; Farraway believes that workforce stability may have led to political pressure in delaying the requirements for LED directional lamps.

For Farraway, the real culprit that the Regulation should be addressing is the AC-mains powered MR16 lamps with a GU10 base that is often referred to as a GU10 bulb. "It is inefficient and there are options available today," he says. Although the price differential is a factor of 3.5–4 today, the price will decrease as volume increases for an affordable product that can last 40,000 hours, compared to an incandescent bulb's 700 hours.

Education, not legislation

A lax legislation will dilute lighting qualities and so disengage the end user. "We need education, through legislation," Farraway says. Another example of the dilution of quality is in the area of directional lighting, he claims. Initially, the cone angle was 30°; now it is 90°, which is not directional lighting, he contests. "This plays to the manufacturers who cannot produce a quality light into a small area, to the benefit of the [older] LED technology."

Peter Hunt of the Lighting Industry Association believes that jobs may be at risk.

He is also mindful of the lack of policing, pointing out that although US and Asia markets may have a similar implementation to the EU, the same product from one manufacturer can, in theory, achieve different ratings in different regions, compromising the quality marks. Whether there will be an optimized-US and an optimized-EU version of products will depend on demand, he says.

> "One of the reasons that LightingEurope is in favor of delaying the effective ban on halogen is the potential impact on jobs within the EU."

Distributor Avnet Electronics, which has a lighting design service and a business arm, Avnet Abacus, specializing in lighting products, is also keen for a universality to be brought to the Regulation and industry in general. Georg Steinberger, vice president, communications at Avnet Electronics, says, "Although we cannot comment on EU policies or industry body policies, of which we are not members, it is obvious that LED technology is the lighting technology of the future... It would be desirable if the World Customs Organization and the EU would come to a technically sound and fair decision on the treatment of LEDs and LED modules, which today in many countries are classified differently and create unfair trade barriers to market participants."

All factions agree on the energy-efficiency benefits of LED bulbs and the case for using them is not questioned. With critics on both sides, the one certainty is that the different viewpoints are seemingly set to be pitted against each other in the next EcoDesign revision, although many are building up a case for their position now.

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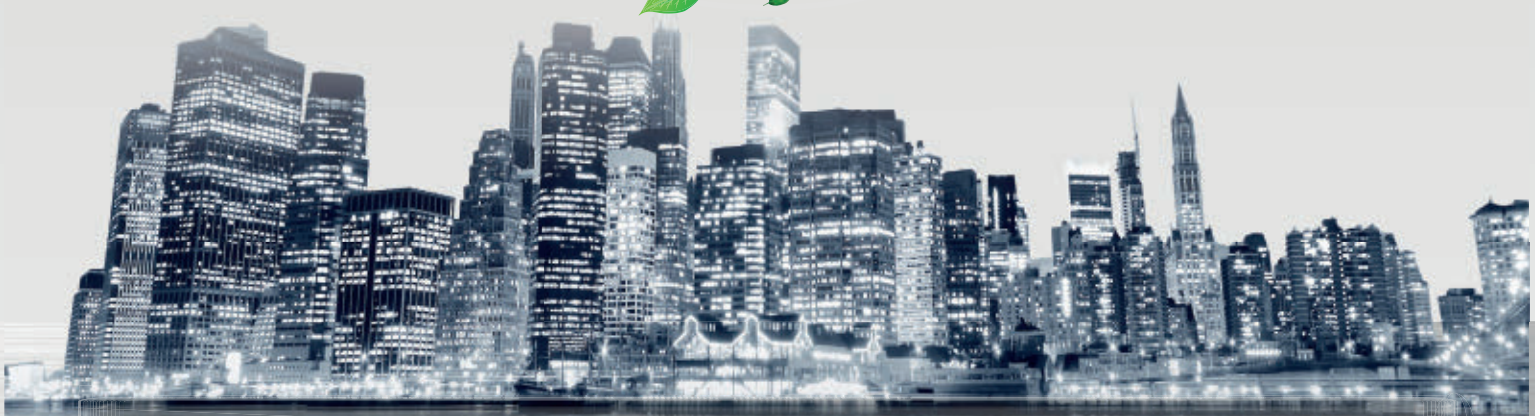

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LED modules advance in performance, standardization questions persist

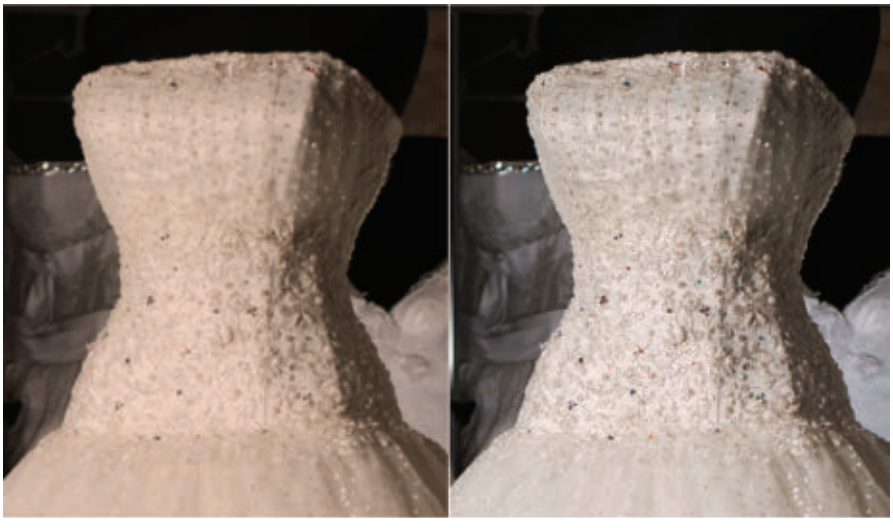
Modular LED light engines can without question accelerate SSL product development, especially with the better color consistency offered today, reports **MAURY WRIGHT**, but the market remains fractured with a mix of proprietary and Zhaga-compatible products.

Many of the largest names in the LED industry now offer modular light engines, alongside specialty vendors that have nurtured the segment. In many cases, simplicity of system design drives solid-state lighting (SSL) manufacturers to utilize modules. But the module makers believe that the technology can also deliver superior performance, especially in areas such as color consistency. The unanswered question in the segment is whether the Zhaga Consortium standards will enable the vision of standardized interchangeable light engines that deliver benefits from the supply chain to field service/upgrade of luminaires.

SSL manufacturers face a shortlist of questions when considering whether to use a modular light engine in a product or to design their own light engine. If the module route is chosen, the development team must then decide whether to buy a module with an integrated driver, choose a separate off-the-shelf modular driver, or design their own. The other decision points include criteria such as modules that use phosphor-converted white LEDs or modules with blue-pump LEDs and remote-phosphor optics. And the last decision point is whether standardization and Zhaga are beneficial to the project. This article will discuss all of those questions.

First, let's address what qualifies as a module or modular light engine. The list includes products ranging from a circuit board with LEDs installed to more finished modules in an enclosure of some type. Modules are available for products ranging from streetlights to ceiling troffers to track heads and more. Modules can require tools and fasteners to attach into a fixture or in cases can be snapped or twisted into place.

Modules may or may not have integrated optics or driver electronics. Zhaga, for instance, refers to light engines with separate or integrated control gear when identifying whether or not a driver is included in a module. For more background on Zhaga, see ledsmagazine.com/features/9/7/15 and ledsmagazine.com/features/10/2/3.



A dress lit by standard LEDs (left) and a Xicato Vibrant module (right).

Why modules?

Traditionally, modules have been thought of as a way to develop products faster in the electronics industry, whether the application at hand was a computer or an LED-based luminaire. In the SSL segment, larger Tier 1 companies have tended to design their own light engines for each product, whereas smaller companies were more likely to choose a module to hasten the development process.

The projected demand and cost of a product also comes into play. Paul Scheidt, product marketing manager at Cree, describes how that company offers customers three levels of engagement at the luminaire design level. When a company isn't sure a project can justify a custom design, Scheidt said that a module is a good option that reduces engineering cost upfront but might result in a slightly higher bill of materials (BOM) in the production phase.

Chip-on-board (COB) LEDs are easier to design into a custom light engine than individual emitters, according to Scheidt, and fall into a middle ground in terms of functionality and cost. Scheidt said that individual emitters properly applied generally perform the best, and in high-volume luminaire production they have the lowest BOM but the highest upfront engineering costs. Ironically, some people have the mistaken idea that COB LEDs produce more uniform light than individual emitters. While it's true that COB LEDs are easier to work with, you can better control the light with smaller sources when a product is designed properly.

GE third-generation Infusion module family.

GE Lighting reports that customers of its Infusion modules follow the traditional thinking thus far. John Koster, product manager for LED modules, said that Tier 1 customers generally find a module too expensive, although he admits that GE focuses on high-performing products more than low cost with Infusion. Koster said that GE has around 20 OEM customers for Infusion that he described as Tier 2 players in lighting.

Changing the decision point

Dave Lidrbauch, product marketing manager at Osram Sylvania, sees the justification changing for choosing the modular route. A key challenge for SSL manufacturers is the pace of change in LED components. Lighting manufacturers want to use the latest LEDs and deliver top efficacy. But the manufacturers also need to offer a product today, and a product two years from now that may use different LEDs, with both looking identical in terms of light output, color temperature, and CRI. Lidrbauch said that you can buy a module from Osram, and Osram will ensure the consistency in its next-generation module.

As for customers, Lidrbauch said Osram is shipping a module in high volume to a Tier 1 customer. Moreover, he said that Osram often works with a close luminaire partner in developing a new module, thereby assuming much of the risk in the design. He recounted one project where Osram had to change the LED being used in a module deep in the development cycle with the customer/partner counting on the module. But Lidrbauch said the process was transparent with the customer involved in the decision. And testing had revealed that the chosen LED would not deliver on the customer's performance requirements.

Therein lies another issue with light-engine design. The LED industry has made great progress with LED manufacturers performing LM-80 testing and providing TM-21 projections on lumen maintenance. But quite often, a development team will need to start a design before there are the 6000 hours of component testing in place required for an LM-80 report. Lidrbauch said, "Designs are almost always started before LM-80 is complete." Still, the latest LED technology promises the best efficacy, lifetime, and color and lumen maintenance. Lidrbauch's message is leave the light engine design to experts who do that job every day.

Chasing quality

Xicato also has a strong opinion on modules as the company is specifically focused in that area. Thor Scordelis, manager of global product marketing, said, "Our focus started with a building with people inside it, and those people looking at surfaces and one another." The point is that lighting needed to render those images perfectly. From the start Xicato focused on "initial and maintained color consistency." According to Scordelis, the chase for quality impacted every facet of Xicato's designs, even the depth of the modules.

Scordelis and Xicato are not Zhaga proponents, and we will get to that discussion shortly. But he pointed out that the mechanical dimensions of the various Zhaga modules defined in Books (specifications or standards) would not allow for a design such as is offered by Xicato.

Of course, the choice of remote-phosphor technology drives the need for a deeper module in Xicato's case because you need a mixing chamber behind the optics. But Scordelis said that the Xicato products deliver top quality in the industry focused specifically on accent lighting. Remote phosphor with the phosphor-coated optic placed away from the heat of the LED junction is a key part of the design story because heat changes phosphor characteristics over time. Moreover, Scordelis said that the aluminum housing Xicato uses in its modules helps keep the phosphor cool and that the efficacy advantage of remote phosphor enables use of lower-power light engines and eliminates the need for heat sinks.

Cree, conversely, has supported remote-phosphor designs and has substantial IP in the area (ledsmagazine.com/news/8/12/24), yet has maintained that white LEDs are the superior choice in most applications, especially in BOM cost. The company contributed an article on the topic last year (ledsmagazine.com/features/9/7/6).

Cree's Scheidt said that part of the cost issue is that remote-phosphor designs need royal-blue LEDs from a single bin to maintain color consistency. Scordelis, however, said that Xicato uses LEDs across bins but would not say exactly how the company keeps the module output consistent.

Spanning a range

Xicato also enables lighting manufacturers to build a single luminaire, stock a range of modules, and deliver products across a variety of performance scenarios. The company offers its modules across a range of CCTs — that's very common — and in a baseline 80 CRI. But Xicato also offers the products in 95-CRI versions called the Artist series for applications such as retail.

Recently, Xicato announced the Vibrant series (ledsmagazine.com/news/10/7/14) that uses the Gamut Area Index (GAI) metric for color quality developed by the Lighting Research Center (ledsmagazine.com/news/7/6/8). CRI actually penalizes a light source that performs better than the incandescent lamp in terms of making saturated colors pop. But in some applications, including museums or retail, that's exactly the desired effect. The Vibrant series only has a CRI of 80 but a GAI of 111. A lighting manufacturer can match luminaires to a wide range of applications with the three classes of Xicato modules.

Enabling a range of luminaires with a module family is also an attribute of the new Gen2 FastFlex modules from Philips Lighting (ledsmagazine.com/news/10/9/19). The

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linear products measure 216×49.5 mm with 16 LEDs mounted in a 2×8 pattern, and target outdoor and high-bay lighting.

To support a range of luminaire designs, Philip offers the typical choice of CCT and CRI but also supplies different optics that can be mated to the light engine. Those optics can come in versions that support a number of different beam distributions ranging from popular streetlight patterns to floodlighting.

Philips Gen2 FastFlex modules for outdoor and high-bay applications.

Driver or not?

Moving to a discussion of integrated or separate driver electronics, we get to a point that really applies across every question we are discussing here. Often the application dictates your choice. For instance, Cree offers the LMR2 downlight modules with an integrated driver and the LMH2 module with separate driver.

While both of the Cree modules target downlights, the LMR2 targets retrofit of existing cans, and, as Scheidt points out, there is no place to mount a separate driver in such an application. Moreover, in a retrofit scenario, dimming requirements will generally be compatibility with triac and electronic phase-cut dimmers so that functionality is simply included in the integrated driver. The LMH2 targets commercial applications and new construction. And a separate driver allows for the option of specifying a driver with the capabilities required for a specific project — such as DALI (Digital Addressable Lighting Interface) or Lutron EcoSystem controls.

GE's Koster said that the first-generation Infusion modules integrated drivers. But the company soon realized that it would need to segregate drivers to get to higher-lumen packages in the relatively compact modules that meet Zhaga Book 5. Now GE offers some of its own drivers and also has an approved third-party driver list for use with Infusion.

The Zhaga standard

Speaking of Zhaga, that industry organization looms as either one of the key developments that can push the SSL industry forward and broaden deployment or as a fractured set of standards pushed by individual companies that will become an afterthought. As always, the end result is probably somewhere in the middle.

As discussed in our earlier Zhaga-oriented articles (links presented previously), standardized modules can provide some advantages. Luminaire makers may have multiple light-engine vendors from which they can choose products, thereby simplifying the supply chain and eliminating engineering costs. Zhaga could allow for simple upgrades to a product line and perhaps simple replacement of modules in the field much like we change lightbulbs today. But there is already a relatively long list of different Zhaga standards, and it will get longer.

Xicato's Scordelis finds little to like about Zhaga. He said, "It's a closed manufacturers' standard," referring to the fact that each of the Books was driven by a company that had a vested interest in the specifics of that form factor. But in fairness, Zhaga is publicly publishing the specifications one by one so that even non-members can use the Books (ledsmagazine.com/news/10/2/20).

Still, Scordelis said that "LEDs will be a fundamentally different technology soon," referring to the early stage we are in with SSL. And he said the concept of replacing a light engine in the field is misguided because you will always need to replace a matched light engine and driver together to maintain quality.

Cree is playing both sides of Zhaga. The company participates and is making moves such as supplying COB LEDs with a light-emitting surface (LES) size that matches Zhaga Book requirements so its customers can deliver Zhaga-compliant modules. But Cree has no plans to sell such modules. Scheidt said that supporting mechanical and electrical compatibility and interchange is just not a core competence, and Cree will focus on more simply designed modules that it can use to help bring lighting companies that are struggling with LEDs into the SSL market.

Zhaga success and obstacles

Philips is arguably the strongest proponent of Zhaga with by far the most modules in Zhaga's certified product list. Back at Strategies in Light, director of experience design Brad Koerner said Zhaga will ultimately allow lighting modules to be treated just like another material in building architecture with lighting systems manufactured on a building site (ledsmagazine.com/features/10/3/7).

Osram is a major player in Zhaga as well. And with that company we are seeing some of the projected benefits of standardization. The Osram PrevaLed Cube modules are essentially versions of a module initially defined by Philips. But while Osram's Lidrbauch applauds the form factor definitions formalized by Zhaga, he insists it's the secret sauce in module design that maintains lumen and color consistency over generations, which will make modules a bigger factor in the SSL industry.

GE, meanwhile, has been one of the longest tenured Zhaga members. GE's Koster said that the company is the strongest proponent of socketable light engines within Zhaga and led the development of Book 5 for socketable light engines. Koster believes the technology will ultimately allow users to change out light engines just as they do lightbulbs and upgrade their lighting to the latest LED technology.

Alas, Book 5 has been the toughest to get started in terms of a fully Zhaga-certified class of products. The more complex twist-and-lock mechanism that makes electrical and mechanical connections has been tougher for certification labs to deal with. But Koster expects GE's Gen2 and Gen3 Infusion modules to be certified soon.

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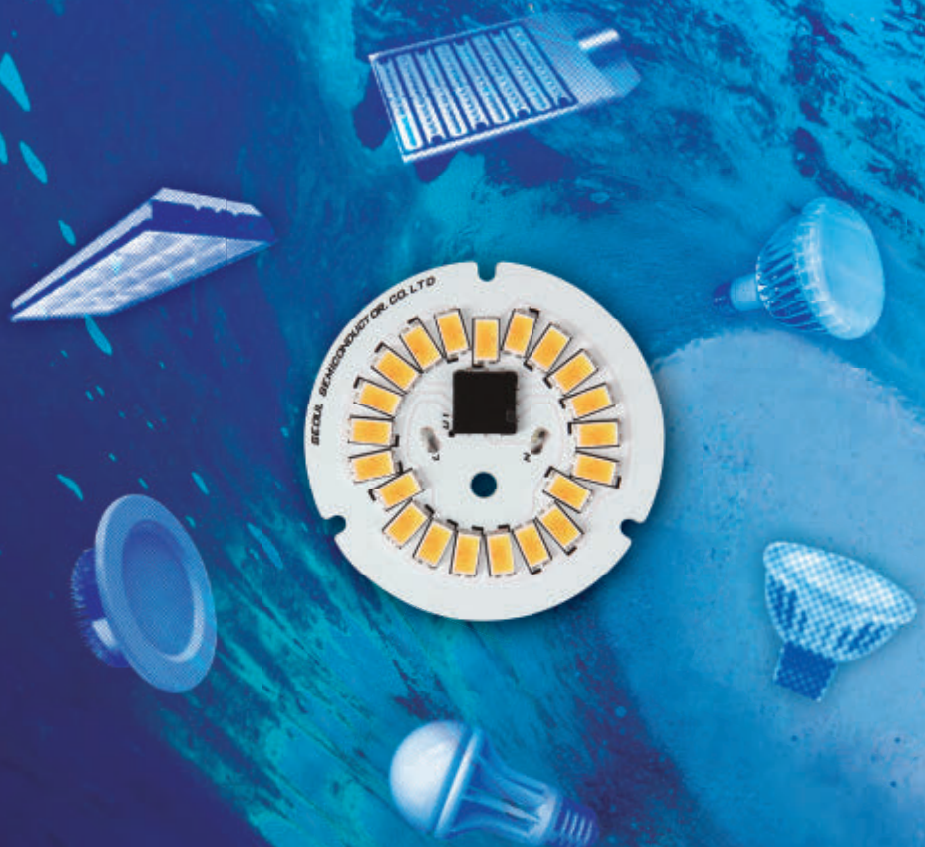

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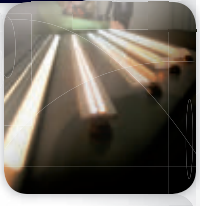

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Careful design delivers halogen-like LED dimming

Enabling LEDs to follow the black-body radiation curve isn't black magic, and **UWE THOMAS** explains a successful approach to the challenge of dimming SSL products to warm CCTs.

People are comfortable with the familiar, uncomfortable with the unexpected. When a halogen or incandescent lamp is dimmed, less current passes through the lamp filament. The filament cools down, producing a warmer light with a greater proportion of radiation at the red end of the spectrum. As a result, we are conditioned to expect that dimming a lamp will produce a warm, relaxing ambience. LEDs produce light through a different physical mechanism — electroluminescence rather than incandescence. Here there is no significant color temperature shift when the current that passes through an LED die is reduced in order to lower its lumen output. You must design LEDs and solid-state lighting (SSL) systems to dim like halogen lamps.

Directional halogen lamps are popular in hospitality environments. But in these applications, the well-documented benefits of LED lighting over halogen lamps are desirable. In particular, LED light sources are far more efficient at converting electricity into light, so they save energy and run cooler. However, making an LED source dim with a similar color shift to a halogen source, maintaining color quality along the way, has presented significant technical challenges to designers of LED emitters and fixtures.

The aim has been to find an LED emitter that closely follows the idealized black-body curve as it dims. Better still would be one that follows the curve even more closely than halogen sources. To understand how this is achieved, it is important to consider the specific requirements for LED die, substrates, optics, and control electronics that make the halogen-style dimmable, directional LED fixture technically possible and commercially viable.

UWE THOMAS *is VP product management at LED Engin.*

Why halogens dim as they do

First let's examine in more detail how a legacy source works. We all know that when we heat a piece of metal it glows. The glow is thermal radiation, a type of electromagnetic radiation, caused by the thermal motion of charged particles in the metal. The color of the glow moves from red through orange, yellow, white, and eventually to blue. While the brightness of the glow will vary with the material in question, the spectral distribution will not; it depends only on temperature. A black body refers to an idealized body that absorbs all of the electromagnetic radiation that strikes it; it doesn't transmit or reflect energy. When a black body is heated, the frequency, or color temperature, of radiation it emits can be plotted in accordance with an accepted formula — Planck's law of black-body radiation (Fig. 1).

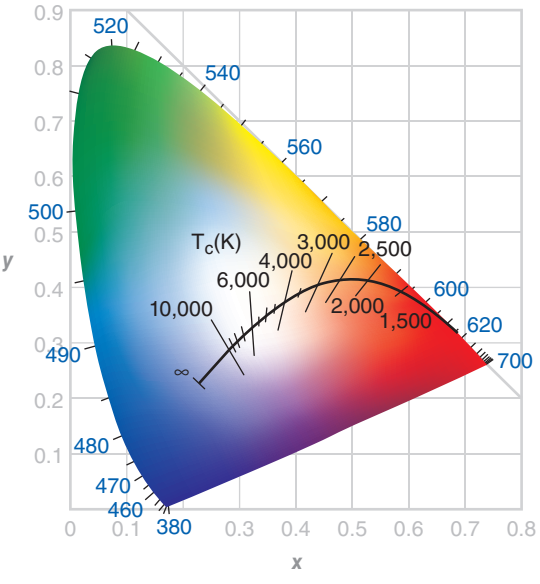

FIG. 1. When a black body is heated, the color temperature (T_c) of radiation emitted can be plotted in accordance with an accepted formula: Planck's law of black-body radiation.

Halogen lamps function by passing an electrical current through a tungsten filament suspended in a glass envelope. A small amount of iodine or bromine (the halogen) is contained within the envelope and this ensures that evaporated tungsten is deposited back onto the filament, rather than on the inside of the glass envelope. The light emitted from the tungsten filament follows the idealized black-body curve quite closely but does deviate somewhat from the ideal black-body curve, producing a greenish tinge at some temperatures. Color quality, defined in terms of color rendering index (CRI), is well maintained by halogen lamps as they dim.

Why LEDs dim differently

The light from an LED is not created by thermal radiation. LEDs create light through electroluminescence. Light is emitted when electrons and holes recombine in a material, most commonly a semiconductor. The spectrum, or color, of light emitted is determined primarily by the constituent materials of the semiconductor and by phosphors — chemicals used to coat the LED die. As a result, when an LED dims as less current is passed through it, the color temperature shift is very small because thermal

radiation represents a negligible portion of the total light emitted. In fact, the hue change as an LED dims is hardly discernible to the human eye.

We're accustomed to halogen-like dimming, and to the high CRI of halogens being maintained as they dim. CRI is most noticeable in skin tones. With consistent CRI, skin tones remain natural as the light level is reduced. The human eye is incredibly sensitive to color change, much more so than to small changes in brightness. During the day, we're most sensitive to blue light and it's from this that we get a great deal of our sensitivity to color shift. We identify detail through the green and red regions of the spectrum and perceive luminance changes primarily within the green part. Incidentally, pure white is, by definition, 76% green, 22% red, and 12% blue light.

We're used to halogen dimming; we feel familiar and comfortable with the effect and if a light dims without appearing to create a warmer white, it feels unnatural

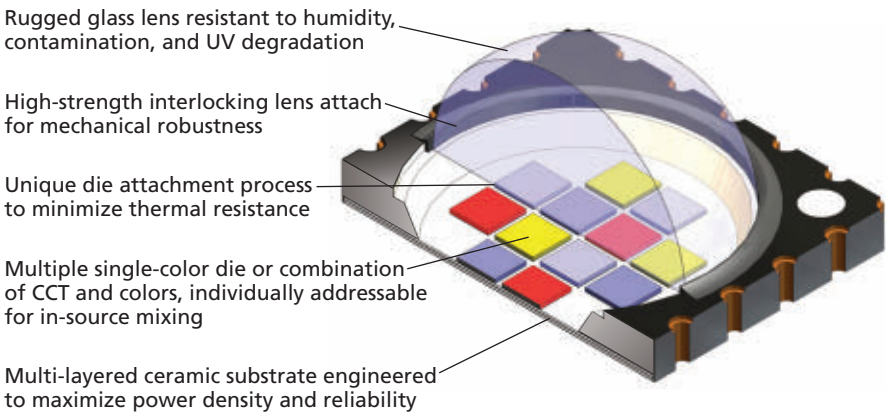

FIG. 2. A combination of proprietary technologies enables these compact emitters to produce consistent, high-quality light that can be precisely focused using secondary TIR lenses.

— something that's very undesirable in a hospitality environment such as a restaurant, bar, or hotel.

Which vital characteristics count?

If we are going the change the color of an LED light source along the black-body curve or other profile as it dims, we must mix the light from at least three types of die to produce a range of white tones, or color temperatures. To make a white LED emitter, you coat a blue LED die with a combination of red and yellow phosphors. Most commonly, die that produce light at 445–455-nm wavelength are used, but those that produce longer wavelengths may be adopted. The combination of die wavelength and yellow/red phosphor recipe is used to achieve the desired color points.

Phosphors may be sprayed onto the LED wafer before it's sliced up to create the individual die, or printed directly onto the die. The latter method creates a direct thermal path for the phosphor layer, helps the phosphor run cooler, and produces more consistent phosphor characteristics. In such instances, the light from the die may be matched to within 3 MacAdam ellipses. Combining multiple different die/phosphor configurations can produce color temperatures ranging from 1800K to 5500K when mixed within a single high-density package.

In order for light to be mixed effectively, the LED die must be closely packed on the substrate. Passing current through the LED creates heat, which has implications for stability over its operating life, but limiting the current reduces the lumen output. This tradeoff can be tackled in two ways. Rather than using an adhesive to attach the die to the substrate, which creates a significant thermal barrier that limits effective dissipation of heat from the LED die, it is better to adopt a proprietary technology that uses a gold eutectic die-attach process with

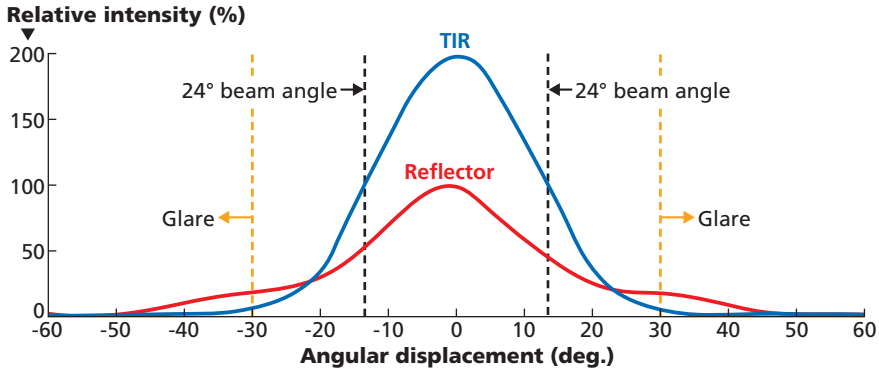

FIG. 3. Intensity distribution over viewing angle is compared for the LED Engin TIR and conventional reflector technology. The compact emitters with TIR lenses produce double the lux-on-target and create minimal glare.

much better thermal conductivity. If a multilayer ceramic substrate with a coefficient of thermal expansion (CTE) closely matched to that of the LED die is employed, it will minimize stress as the die heats up.

This combination of technologies enables die to be driven at higher currents, producing more light from smaller packages, without reaching damaging junction temperatures. Where a glass primary lens is used on top of the die it will not degrade over time as a silicone lens would, so color stability is maintained throughout the operating life of the emitter. Color mixing starts close to the die and can be completed using carefully matched secondary optics that also enable tight focusing of the beam through a total internal reflection (TIR) design (Fig. 2). A consistent quality of light is then achieved across the beam.

It has been demonstrated that compact emitters used with matched secondary optics can deliver twice the lumens-on-target compared with conventional emitter/reflector combinations (Fig. 3). Furthermore, the compact emitter/lens combination produces a smooth beam edge and minimizes light emitted outside of the target area, reducing unwanted glare. This is an important requirement in hospitality and other professional lighting applications.

Combining a driver control

The emitter and emitter/lens technologies described previously can be combined to underpin a tunable white LED platform. For example, LuxiTune developed by LED Engin is available as an emitter plus secondary TIR optic and integrated driver (Fig. 4). The module reduces the time taken by

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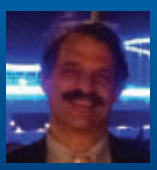
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FIG. 4. A compact emitter, secondary optic, and driver control board make it easy to implement halogen-style dimming with all the benefits of LEDs.

lighting fixture manufacturers to bring new products to market.

In this instance, the single emitter consists of 12 die driven via 3 channels, i.e., 3 groups of 4 die. The substrate design actually enables each LED die to be driven independently. The secondary optics create beam widths of 24°, 32°, or 45°, with minimal wasted light or glare.

The printed circuit board upon which the emitter is mounted to complete the module carries the control electronics that determine the relative drive to each group of die. By triangulating the light from each group, the color temperature is varied from 3000K at the highest lumen output to 1800K fully dimmed to below 2% of maximum output (Fig. 5). The control board incorporates an interface circuit to industry-standard, widely available, and low cost 0–10V dimmers or push-button controls. DMX interfaces are optional. This platform runs from a single, unregulated 24V power rail. AC-DC power supplies that deliver this voltage are readily available at low cost.

Control is achieved using proprietary algorithms running on a microcontroller. The programming ensures consistent color temperature and flux throughout the operating temperature range and no recalibration is ever required.

The processes and technologies described earlier ensure that emitters are of consistent color temperature to within 3 SDCM (Standard Deviation Color Matching) or MacAdam ellipses, so fixtures throughout an installation will deliver the same performance. At 3000K, a CRI of 90 and R9 of 80 can be achieved and across the dimming range the CRI average is 85; the red component, R9, averages 70. Typical output is 1100 lm and at stable temperature from the TIR lens. Power consumption is 17.3W for a luminous efficacy of 63 lm/W.

At maximum output, such emitters are approximately equivalent to 60W halogen sources but with up to 70% energy savings. A further benefit is that they run much cooler than halogens, eliminating the safety hazards that high-temperature fixtures can pose.

Proprietary technologies for selecting and coating LED die, attaching the die to the substrate, substrate design, primary and secondary optics design, and control electronics have now been combined to create easy-to-implement solutions for producing halogen-like dimming from compact, efficient, and economical LED sources.

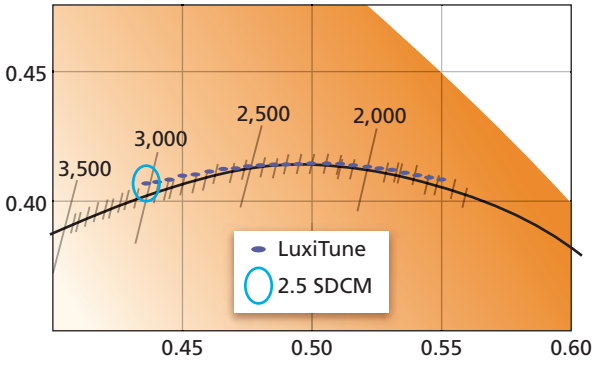

FIG. 5. LuxiTune's CCT tracks the black-body curve closely.

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Increase LED driver efficiency without a sense resistor

Seeking to improve driver efficiency for portable power applications, **CHRIS GLASER** and **JIM CHEN** explain a voltage-regulation technique known as high-side sensing, which eliminates the lossy sense resistor component by relying on a MOSFET.

Unlike most DC/DC converters that regulate the output voltage, an LED driver regulates current in the LED. The LED current is proportional to the light output, and the light output is the key concern for an LED driver. To regulate the LED current, traditional LED drivers have regulated the voltage drop across a discrete current sensing resistor. Since the entire LED current must be routed through this resistor to develop a measurable voltage, this sense resistor is an important loss term in these LED drivers. This article discusses a technique for regulating LED current without the need for this lossy sense resistor. This increases LED driver efficiency, which is critical for portable power applications in consumer and medical end equipment.

The light output of an LED is proportional to the current through the LED. So to achieve a controlled light output, the LED's current must be controlled. The user also typically wants to dynamically adjust light output during operation. Practically, this might mean adjusting the backlight's brightness on a smartphone or glucose meter in order to better read the display in bright light or at night. This dimming capability requires a tight control over the regulated current in the LED, in order to accept user inputs and make slight changes to the light output based on ambient lighting conditions.

Regulation using a sense resistor

Regulating the output current accurately presents a challenge for most DC/DC converters, which typically are configured to regulate the output voltage. Measuring the output current usually requires generating some voltage drop across a sensing element or measuring the magnetic field created by a flowing current with a Hall-effect sensor. Hall-effect sensors are bulky, expensive, and not suited for portable applications. Measuring the voltage across sense resistors creates an additional loss in the system; the resulting lower efficiency creates excess heat and a temperature rise, while reducing the battery's runtime.

Measuring the LED current through a sense resistor is frequently chosen because the approach is simple and straightforward. Since the current in the sense resistor is DC, accuracy can be high. However, there is a loss of efficiency with the sense resistor approach.

Fig. 1 shows a typical LED driver block diagram that regulates the current through a sense resistor. The voltage across the sense resistor is compared to a reference voltage, V_{REF}, by an operational amplifier (op amp). The op amp drives a power stage that converts the input voltage, V_{IN}, to an output current, I_{OUT}.

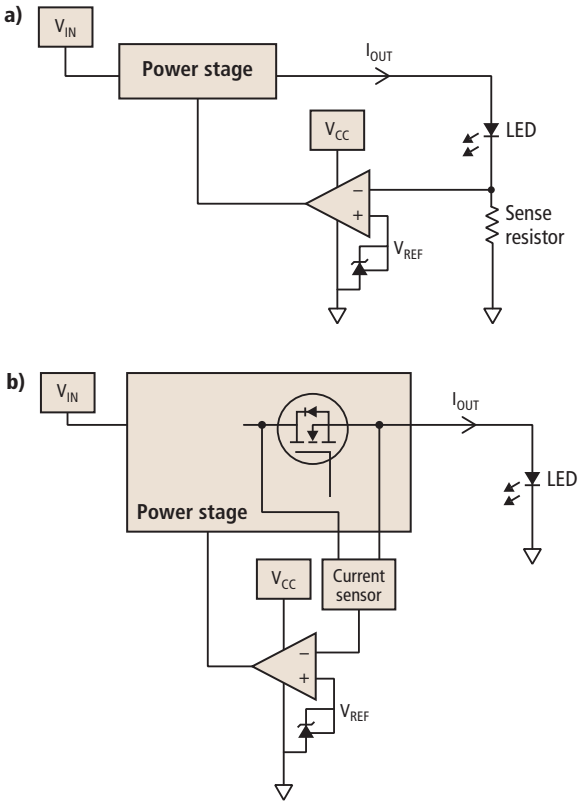


FIG. 1. Comparison of LED current regulation through a) a sense resistor and b) a MOSFET in the power stage.

MOSFET in the power stage

A more efficient approach is to measure the LED current in the power stage. Almost all power stages in LED drivers have at least one MOSFET between V_{IN} and the LED to accomplish the necessary switching action for the given power conversion topology. Since a MOSFET is present, the same MOSFET (or a smaller, sensing MOSFET in parallel with it) may also be used to sense the current flow. Unlike the traditional approach with a discrete sense resistor carrying only a DC current, the current flow in the MOSFET typically is AC. So further processing and manipulation of the MOSFET's current signal occurs to generate an equivalent LED current. Fig. 1b shows this type of topology.

Known as high-side sensing, the MOSFET

CHRIS GLASER *is an applications engineer and* JIM CHEN *is a systems engineer at Texas Instruments.*

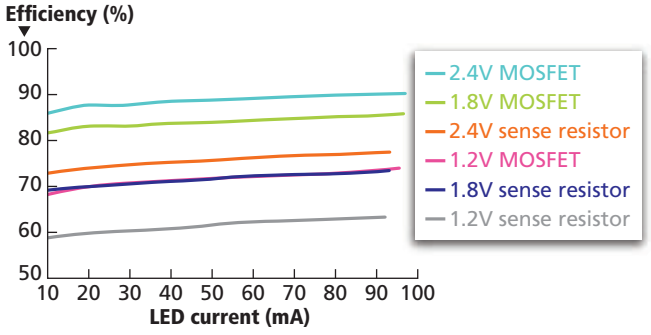


FIG. 2. Efficiency comparison of current regulation methods.

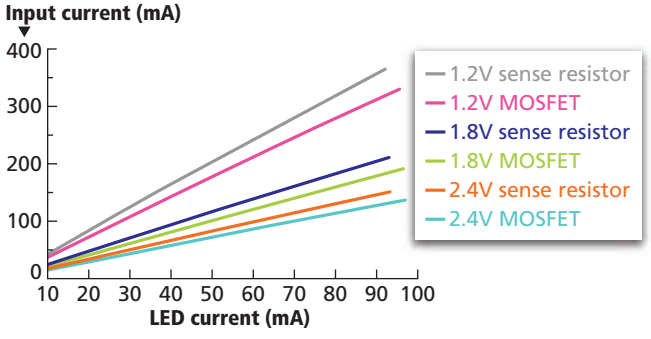


FIG. 3. Input current comparison of current regulation methods.

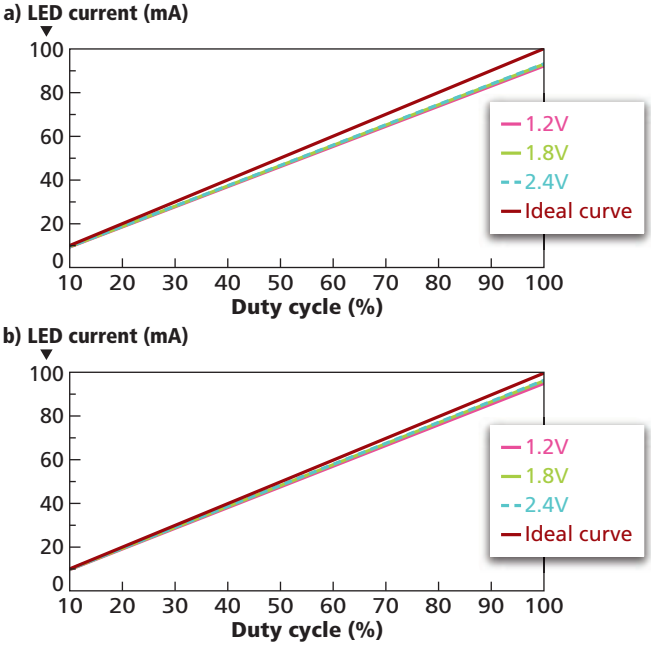


FIG. 4. Comparison of dimming accuracy for a) sense resistor method and b) MOSFET in power stage method.

approach eliminates the sense resistor component and its losses from the system, while allowing the LED's cathode to be connected to ground. This is generally a preferred connection; the system ground is often a large plane and ideal for spreading heat created in the LED. This reduces the LED temperature, increasing its lifetime and increasing the efficiency of the system by eliminating one of the losses (the sense resistor). However, configuring the op amp and current sensor circuitry

to handle the common-mode voltages that occur with high-side sensing is more difficult compared to the sense resistor method.

Comparing the options

To provide a fair comparison, the same LED and power stage should be used to compare the sense resistor and MOSFET in the power stage methods of current regulation in an LED driver. A device that supports both methods is the TPS61260 boost converter. Since the same device is used, the power stage is the same. It is configured to boost 1.2V, 1.8V, and 2.4V input voltages to drive a single LED dimmed from 10 mA to 100 mA. The LED's forward voltage is about 3.1V at 100 mA of current. The op amp and current sensor circuitry for the MOSFET in the power stage method of current regulation is integrated in the device, so this complexity does not appear to the product designer.

The efficiency is calculated by computing the power delivered to the LED itself, which is then divided by the average input power. By using the LED's forward voltage and current as the output power, the losses in the sense resistor are kept out of the output power equation, resulting in lower efficiency. This is an accurate calculation for the system efficiency; the power loss in the resistor is truly a loss because it does not produce light output. Using the LED driver's output voltage in the efficiency calculation is inaccurate; the output voltage includes both the LED forward voltage and voltage drop across the sense resistor.

Fig. 3 shows the efficiency difference of the two methods; Fig. 4 shows the resulting difference in input current drawn. The 0.5V that the TPS61260 regulates across the sense resistor is significant compared to 3.1V forward voltage of the LED, so the efficiency in the sense resistor configuration is significantly lower — by more than 10%. This results in a higher input current drawn for a given light output, which reduces the system's battery runtime.

Dimming accuracy for each current regulation method is compared in Figs. 5 and 6. In both graphs, pulse-width modulation dimming is used to reduce the LED current from its 100 mA full level. Both curves are highly linear; there is some offset in the slope to the ideal curve. Sensing the LED current through a MOSFET in the power stage provides the same dimming linearity as the sense resistor method. This allows the user to have the same control over adjusting the light output to changing ambient conditions.

An LED driver without a traditional sense resistor obtains higher efficiency when an already present MOSFET in the power stage is used to sense the LED current. This simplifies the circuit by removing the sense resistor component, allowing the LED a connection to ground — gaining better thermal relief and longer lifetime. Higher efficiency translates into longer battery runtime in typical portable consumer and medical end-equipment in which a single LED driver is used.

Optical silicones enable LEDs to compete for lighting applications

KAZ MARUYAMA, global industry director for lighting solutions at Dow Corning, states that the choice of silicone materials in LEDs can enable a more cost-effective efficacy boost than chip innovation in some cases.

As LED chips quickly approach their theoretical limits for efficient light output, incremental improvements to the LED die provide diminishing returns on investment. This presents a dual challenge to LED manufacturers, who are feeling the pressure to optimize the lumen-per-watt efficacy of their devices while simultaneously driving down costs. This challenge is particularly acute for manufacturers competing for the rapidly expanding opportunities in general solid-state lighting (SSL) applications — but optical silicones can help.

Lighting consumes nearly 20% of global electricity generation, according to the United Nations en.lighten initiative. This fact has not only prompted governments around the world to plan or implement stringent new energy-efficiency regulations, it has sparked growing competition from LED manufacturers for a share in the expanding general lighting market.

As designers look beyond the technological status quo to boost lumen output and streamline costs, many are showing interest in optical silicone technology. As a class of materials, silicones are driving greater reliability, performance, and cost efficiency in applications spanning the entire LED value chain. Easily molded, these versatile materials are finding application as optically clear encapsulants or highly reflective LED packaging elements. In either case, silicone technology offers expanded design latitudes for shaping light and improving LED reliability.

Silicones also deliver high thermal and photostability compared to organic materials, such as epoxies or plastics. This stability is an important consideration as LED designers increase the amount of drive current in their devices and decrease the overall size of lighting fixtures. Combined, these trends are pushing LED temperatures to 150°C and higher, which can cause conventional epoxies and plastics to turn yellow and physically degrade over time. In contrast, silicones have demonstrated reliable optical and physical performance at temperatures reaching 200°C and higher. This range helps ensure next-generation LEDs can meet and exceed the lumen maintenance requirements of challenging packaging applications.

Many LED manufacturers may already be familiar with these properties of silicones. Yet many are unaware that not all optical-grade silicones are created equal. While all silicones share the same basic silicon-oxygen building blocks, they actually fall into two distinct chemistries characterized either by phenyl or methyl end groups distributed along their molecular backbone.

The differences between phenyl and methyl chemistry pose significant real-world implications for LED manufacturers. Namely, phenyl-based silicones deliver a comparatively higher refractive index (RI) of 1.54 vs. the 1.41 exhibited by methyl-based technologies. Although small, this difference in RI can translate into about 7% more light output — independent of the LED chip, case, or input power.

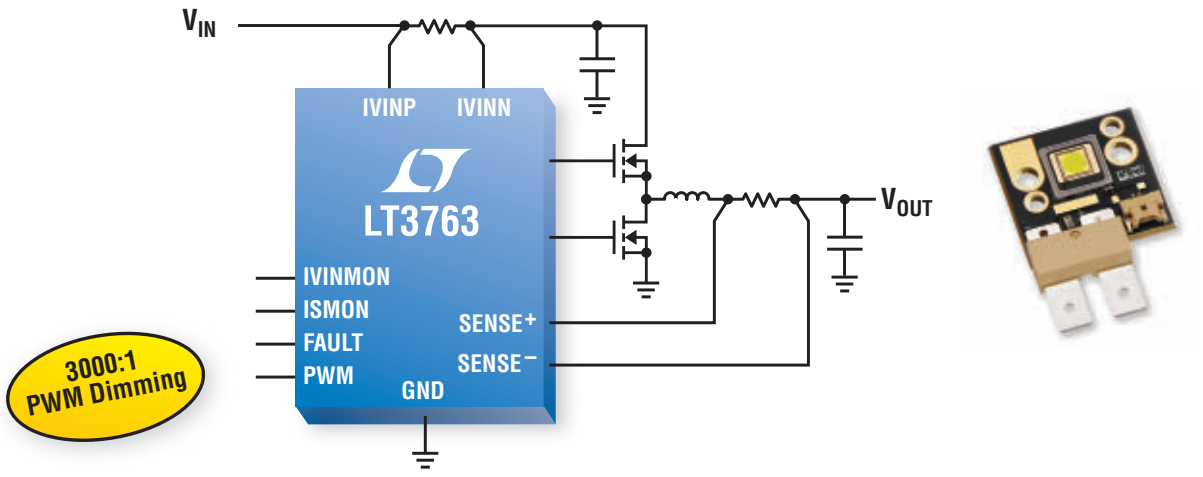
In other words, phenyl-based optical silicones enable LED designers to boost LED output simply by changing encapsulant materials. Such a materials choice signals a more cost-effective alternative to achieving a comparable improvement in LED chip performance.

Traditionally, the view among many veteran LED designers and manufacturers was that phenyl silicones came with certain limitations when it came to thermal stability — but no more. Breakthroughs in phenyl-based silicone chemistry now enable optical silicone encapsulants to perform with exceptional reliability in the latest generation of chip-on-board LED architectures.

Further, phenyl-based silicone encapsulants provide comparatively higher mechanical strength, and stronger gas barrier properties. This quality is particularly important for protecting delicate LED components such as phosphors or silver electrodes against moisture deterioration and sulfur corrosion. Because LED electrodes double as reflective elements and phosphor is a key element of light conversion, enhanced gas barrier protection is absolutely critical to maintaining both the performance and reliability of LED output.

We expect a key factor in the worldwide growth of LED-based lighting to be driven largely based on the adoption of high-RI materials. Advances in phenyl silicone technology have come just in time to improve the efficiency, reliability, and competitive value of LEDs as manufacturers target new applications emerging in today's general lighting market.

60V_{IN} 350W LED Driver



20A Outputs for LEDs or Current Sources That Are Easy to Parallel

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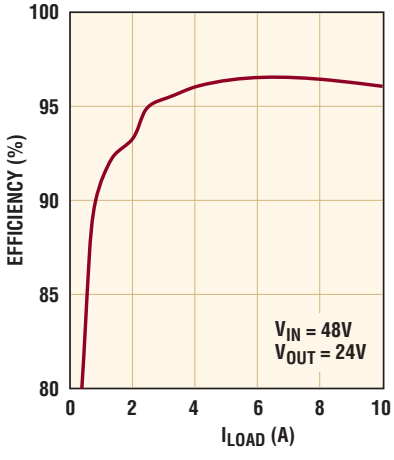
Features

- Accurate Control of Input & Output Current
- 3000:1 True Color PWM™ Dimming
- ±1.5% Voltage Regulation Accuracy
- ±6% Current Regulation Accuracy
- Input Voltage Range: 6V to 60V
- Control Pin for Thermal Control of Load Current

Efficiency vs Load Current



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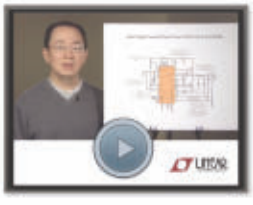

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