JULY/AUGUST 2013

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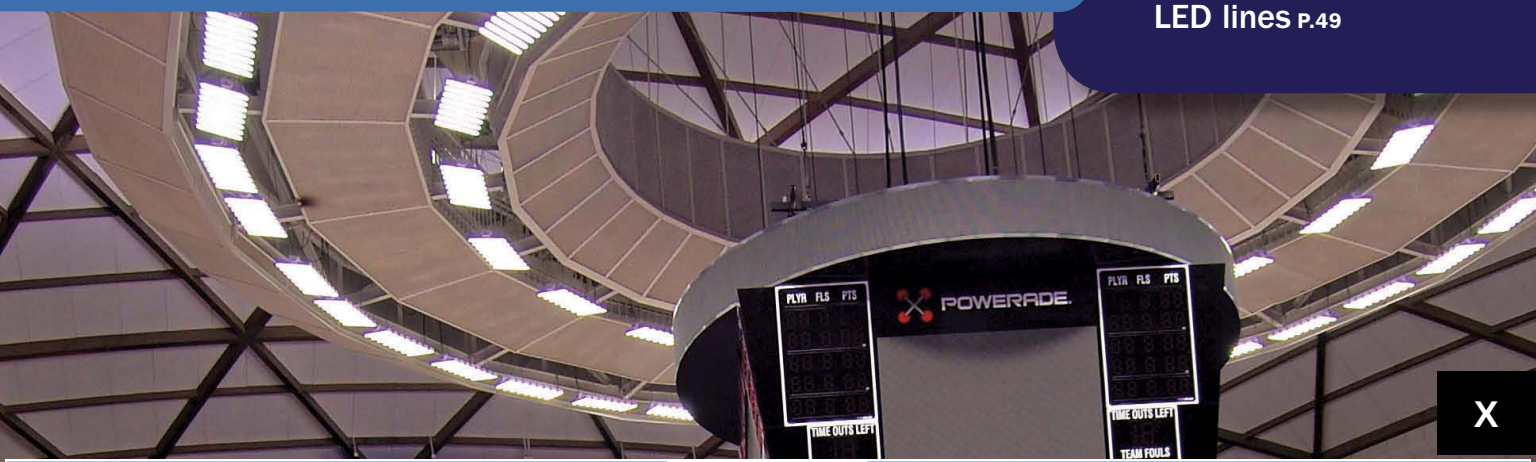

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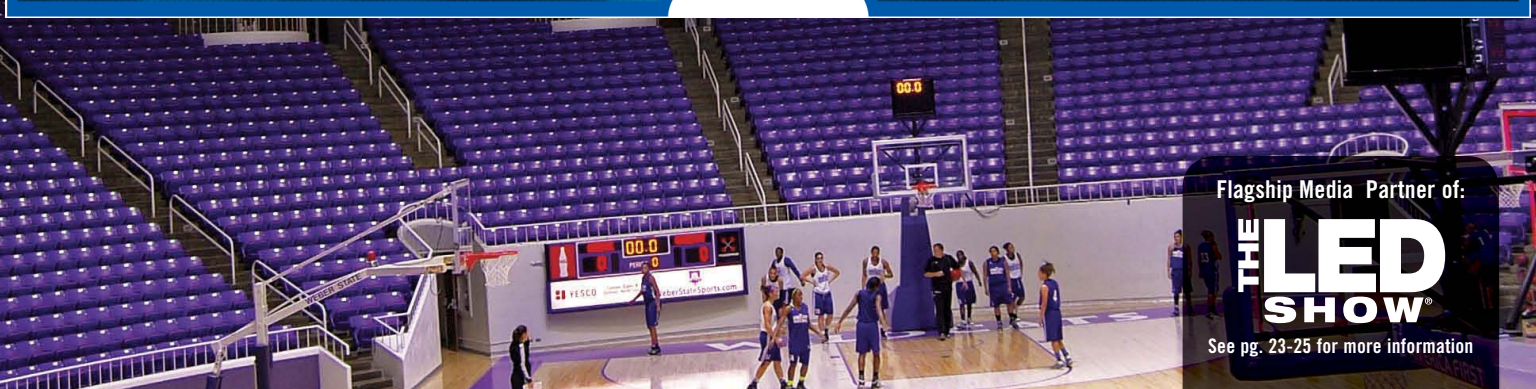

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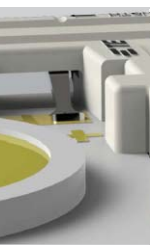
Cover Story

GE Lighting's Albeo business unit supplied the high-bay lighting installed in the Dee Events Center that's expected to save Utah's Weber State University about $40,000 in energy costs annually, and reduce maintenance costs for the difficult-to-reach fixtures (see page 7).



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commentary

Less may become more in SSL product lifetime

Times change quickly in the solid-state lighting (SSL) world. Just two years ago, LED and lighting manufacturers were making hyperbolic claims of 50,000–100,000-hour product lives and many poorly designed SSL products were failing very early. Now a maturing industry can reliably deliver lighting products with such long life, but should they? I've become increasingly convinced that, while exceptions exist, the industry needs to focus on 10,000–15,000-hour lifetimes for many mainstream products.

Don't misunderstand. I applaud the developments of the last few years. The LED industry has embraced LM-80 testing and the TM-21 methodology to project component life. Product developers have learned to implement thermal and driver technology to ensure that SSL systems deliver on long-life potential.

Still, in many cases, the industry will be better off with a more moderate expectation of lifetime. We can ensure a more robust ongoing lighting economy with regularly refreshed product lines and retrofitted installations that still deliver all of the energy-efficiency promises of LED technology.

Now I can't claim this revelation as original thinking. I've heard industry insiders make similar points, so credit where credit is due.

Last year at the Street and Area Lighting Conference, Mark Hand, director of new products and technology at Acuity Brands, discussed how LED products are essentially over-specified for most applications (leds magazine.com/features/9/12/11). Ironically, he presented at an event where long life may make sense. But Hand's point was that specifiers can manage the cost of products by being realistic and only demanding long life, or other premium features such as high CRI, when justified by the application.

Venture capitalist Vinod Khosla took a stronger stance in a Lightfair keynote that I also covered in my column from the previous issue (ledsmagazine.com/features/10/6/3). He simply said long life doesn't matter in most applications, and used 20,000–25,000 hours to characterize long life.

Khosla made his point with a simple image. He showed a photo of a phone that we may have used 25,000 hours ago and asked if anyone still wanted to use that phone today. LEDs are going to enable amazing new form factors and features in lighting products. So even if someone installs a 50,000-hour product today, they are apt to change it long before end of life comes.

If we reduce the expectation to 10,000–15,000 hours, what is the impact? I don't have all of the answers. But we could use fewer LEDs driven harder and slash upfront cost. Maybe we really don't need such complex thermal management in all products. Simpler thermals could lower costs and yield more attractive products.

Obviously, my stance doesn't apply everywhere. Industrial lighting that burns 24 hours a day and is rarely retrofitted warrants products designed for long lifetimes. There is a light fixture on a high ceiling in a basement stairwell at my mother's house that will get an expensive Philips L-Prize lamp, which will probably last 50,000 hours, installed when it next burns out. Clearly, street lights aren't retrofitted often and long life is a huge part of projected payback.

For many applications, less may be more. Even office spaces are often retrofitted more quickly than the lifetimes that are commonplace with new SSL products. So great job to the industry, but let's rethink the strategy in many cases.

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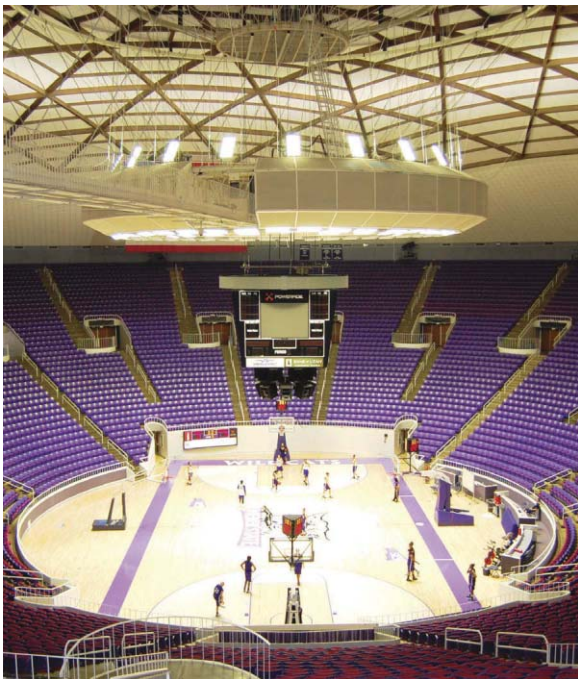
ARENA LIGHTING

GE supplies Albeo high-bay LEDs for Weber State Dee Events Center



GE Lighting announced that its Albeo business unit, acquired in November 2012 (ledsmagazine.com/news/9/11/18), has supplied 80 ABHX-Series solid-state lighting (SSL) luminaires to Weber State University in Odgen, UT to light the campus Dee Events Center. The LED-based high-bay fixtures will save the university $40,000 each year in energy costs, and reduce maintenance cost as well especially given that the lights are very difficult to reach.

Lighting sports venues is one of the last applications where LED lighting has made headway. There are many instances of major sports venues using SSL for decorative or entertainment purposes, or to light areas such as concessions or concourses. The Weber State project, however, may be the most significant use of SSL products in lighting a playing surface.

The roadblock to LED usage in sports-venue lighting has been the light output required and the cost and weight of fixtures that can deliver the requisite light levels. Maturing LED technology has now made the technology feasible in lighting playing surfaces. And LEDs will never have the restrike problem that plagued the NFL Super Bowl after a minor power outage this past February.

OUTDOOR LIGHTING

MaineDOT installs high-mast LEDs

Back in the summer of 2012, we covered the trial of LED-based high-mast lighting by the Maine Department of Transportation (MaineDOT) at a freeway interchange (ledsmagazine.com/features/9/6/6), and now the state has moved forward with a project retrofitting 105 light towers along Interstate 295. MaineDOT ultimately selected Holophane HMAO luminaires from Acuity Brands for the project (ledsmagazine.com/products/38638).

High-mast lighting has largely remained the domain of » page 8

BUSINESS

Panasonic expands LED business in Asia

Japan has been among the fastest adopters of LED lighting, driven in part by the energy crisis that dates back to the 2011 tsunami and nuclear plant disaster. Panasonic has enjoyed success in its home region and has offered ceiling lights in China. Now the company plans to offer a broader SSL portfolio in Indonesia, India, Taiwan, Vietnam, Hong Kong, and China, initially launching the expansion in June with 40 new luminaires in Vietnam.

Panasonic said it will develop fixtures that match the individual requirements of consumers in each market. The company is planning showrooms and distribution agreements in each new region.

As of the end of its recent fiscal year in March 2013, Panasonic said SSL sales outside of Japan totaled ¥3 billion with almost all of that revenue from China. The company plans to double the sales outside Japan in the next three years. ◄

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

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GE from page 7 The Weber State project utilized luminaires designed for industrial applications. Albeo modified the design, developing a bracket so the fixtures could be installed near the ceiling of the arena above and around the ubiquitous suspended scoreboard. The 80 fixtures replaced 100 HID fixtures.

At full power, the new lighting produces more than 200 fc on the basketball court — more than double what the US National Collegiate Athletics Association (NCAA) requires for college arenas. Arguably, as the photo shows, the lights are too bright. But the installation supports nine dimming zones that will allow tuning of the lights for an optimum playing environment.

Jacob Cain, Weber State energy and sustainability manager, said that the prior HID lights delivered 60–150 fc with some dark spots on the floor. The LED lighting is more uniform, doesn't buzz or flicker, and can be dimmed instantaneously for special effects such as player introductions.

While the lighting quality has exceeded the university's requirements, it was energy efficiency that instigated the project. Cain's team begun by looking to see how other institutions had addressed excess energy usage in arenas after documenting that the Dee Events Center was one of the largest power users on campus. The team found no prior usage of LEDs in similar arenas for comparison, but went through a fixture evaluation with Albeo's help and ultimately moved forward with the project.

"Month after month when the electric bill came for the Dee Events Center, all we could do was cringe and pay," said Cain. "The new high-bay lighting gives us brighter light with fewer fixtures, and we spend less money on energy. Now that's something we welcome and our teams and fans can appreciate." ◄

MORE: ledsmagazine.com/news/10/7/1

from page 7 HID sources because of the high levels of light required, and the cost and weight of LED products that could meet the requirements. Typically, there is a cluster of six to twelve fixtures on each high-mast pole.

Ultimately, LED-based products will both improve lighting and reduce energy usage in such applications. The trial we documented a year ago was among the first instances of SSL usage in the high-mast application.

The HMAO fixtures take a modular approach to the challenge of delivering the high light levels. Each fixture includes a number of LED modules and multiple drivers. The design delivers overlapping light distribution, ensuring safe light levels even if one module or driver were to fail.

MaineDOT faced a budget crisis operating the existing high-mast lights placed at freeway interchanges. As we covered in the prior article, the state was shutting the lights off from 11 PM to 6 AM each night to save money. The transition to LEDs delivers both baseline energy savings and the ability to dim the lights at night, and still provides a safe level of lighting throughout the night.

"Our main goal is to provide a safe transportation system for the state of Maine," said Ron Cote, MaineDOT electrical supervisor. "We were looking for a light source that would provide lower maintenance and a whiter light. The benefits of multiple LED drivers and modules and the longevity of Holophane HMAO LED fixtures are exactly what we wanted. Additionally, the quality of light combined with the payback of these fixtures is absolutely incredible."

MaineDOT has documented the energy cost for operating the new lights from dawn to dusk at $66 per month per tower. The prior lights cost $200 per month to operate even with the lights off for a portion of the night. The agency projects ten-year savings of $1.35 million. ◄

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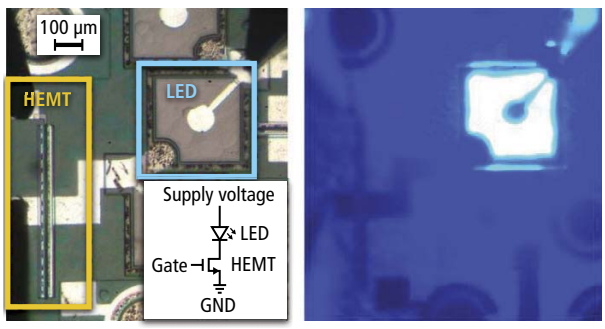
RESEARCH

RPI integrates LED emitters with on-chip electronics

Researchers at the Rensselaer Polytechnic Institute (RPI) Smart Lighting Engineering Research Center (ERC) have integrated a power transistor in gallium-nitride (GaN) layers along with an LED structure. The RPI research is focused on adding functionality to LED chips that can simplify the complex external electronics required to drive the LED. The project involved the monolithic integration of both a high-electron-mobility transistor (HEMT) and an LED on one chip.

T. Paul Chow, an engineering professor at RPI and the leader of the recent research, said, "Eliminating the MOSFET is the first step. We can add the gate driver circuitry, and then more integration to realize a power converter." Chow also said a single HEMT could control multiple LEDs on one chip.



The project utilized a GaN substrate and realized an LED that matches the light density of standard GaN LEDs being manufactured in volume today. The research team compares the development with the evolution of transistors to dense ICs in the silicon semiconductor world, with Chow calling the device a light-emitting integrated circuit (LEIC).

The implication is LEDs that might have complex integrated functions ranging from sensors to perhaps communication capabilities or even low-end microprocessors. Chow added, "We can also integrate some sensors, and eventually a network. However, how much one will do in GaN and how much in silicon nanometer-scaled CMOS is subject to discussions, system or IC partition choices, and sometimes debate."

The study entitled "Monolithic integration of light-emitting diodes and power metal-oxide semiconductor channel high-electron-mobility transistors for light-emitting power integrated circuits in GaN on sapphire substrate" has been published in the scientific journal *Applied Physics Letters*. ◄

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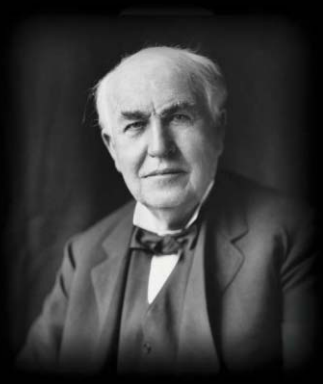

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BUSINESS

Luminus Devices announces merger with Sanan subsidiary Lightera

The merger of Luminus Devices into Sanan Optoelectronics' subsidiary Lightera Corp. will provide the Chinese company with access to much needed intellectual property (IP) that will jumpstart its LED manufacturing operation. Luminus announced the merger and said that it will remain an independent business unit and operate as a subsidiary of Lightera, but did not announce what Sanan and Lightera paid prior investors to seal the merger agreement.

Ella Shum of analyst firm Strategies Unlimited (a sister business to *LEDs Magazine* within PennWell Corp.) wrote about Sanan and the likelihood of China producing a top-ten LED manufacturer in December 2013 (ledsmagazine.com/features/9/12/5), speculating that Sanan could become a top global supplier after seeing some success in Taiwan with low-end LEDs. She also noted that the company needed an IP infusion to compete in high-end LEDs for the mainstream lighting market. Lightera is rumored to have made major investments in LED fab lines in the Silicon Valley area of California.

"As a leader in the specialty lighting market, Luminus Devices provides us with proven, state-of-the-art technology that will allow Lightera to expand both our US and international offerings," said Decai Sun, chairman and CEO of Lightera. "We expect Luminus to continue to focus on new technology, specialty lighting markets, applications, and superior customer service."

"Luminus has been searching for the right partner that would add to our extensive intellectual property, allow for expansion of our global operations and would be additive to our market-leading position in many segments of the worldwide specialty lighting market," said Keith Ward, president and CEO of Luminus Devices. "This relationship with Lightera and Sanan will allow us to expand our capabilities through new access to technical and financial resources well beyond our current position."

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

RESEARCH

Seattle startup looks to replace rare earths with silicon nanoparticles

Researchers at the University of Washington hope to reduce the cost of solid-state lighting (SSL) products via a transition from phosphors based on rare-earth elements to electroluminescent silicon particles derived from sand.

Startup LumiSands has emerged from the Center for Commercialization at the university in Seattle that hopes the silicon nanoparticles can both lower the cost of LEDs and SSL products and improve the light spectrum.

"Hopefully, manufacturers could substitute traditional rare-earth ele- » page 12

INDOOR LIGHTING

Fresh Market installs SSL chain-wide

The Fresh Market is a specialty grocer with more than 100 stores across more than 20 US states, and is in the midst of a company-wide transition to solid-state lighting (SSL) with the aim of reducing energy usage and providing a superior light levels, quality, and spread," says Paul Poole, energy and engineering manager for The Fresh Market. "While saving energy is important to us, an essential element of The Fresh Market's concept is the visual appeal of different foods and

shopping experience for customers. The grocer is replacing 64W halogen lighting with GE Energy Smart 17W LED PAR38 Retail lamps, and has already installed 17,000 lamps.

The Fresh Market initiated the LED project in 2011 working with distributor Illuminating Technologies to evaluate potential LED-based replacements for its halogen lighting. The management team wanted to save energy, but also wanted to preserve the ambiance and improve the quality of lighting on the products. The European-style markets feature an open-air layout with prominent produce bins, meat and cheese cases, and bakery goods.

The grocer sought to test whole-store retrofits from the start of the project. "We didn't just replace ten or fifteen lights in one area of the store — we actually asked suppliers to provide us with three hundred lamps for a complete store retrofit so our executives could properly evaluate the unique environments for our customers throughout the stores."

The grocer plans to complete the company-wide retrofit this year. Prior to the LED transition, a typical store using 312 lamps would consume 107,800 kWh annually. That number drops to 28,600 kWh with the LED lamps in place.

The LED transition is also leading to secondary benefits in energy and maintenance savings. "As we started to replace the old halogen bulbs with LED lamps, we realized we were taking the first stage of heat out of the building," said Poole. "As a result, we don't have to run our HVAC systems as much because less heat is generated from other equipment in the building. Add to that the anticipated time savings from our store managers replacing bulbs — LEDs have a 50,000-hour life compared to halogen's 3,000-hour life — and there is very low risk with this project." ◄

MORE: illuminationinfocus.com/news/4/6/2

news+views

from page 7 ments with our material with minimal additional steps," said Ji Hoo, a doctoral student in electrical engineering and co-founder of LumiSands. "It will be cheaper, better-quality lighting for users." The researchers noted that rare-earth elements are expensive, dangerous to mine, and largely controlled by China.

The team has thus far demonstrated the conversion of blue LED light into red light using silicon particles that are smaller than 5 nm. They believe that they can develop yellow and green particles in short order. The combination of the three and blue LED emitters could deliver a spectrum near that of sunlight.

MORE: ledsmagazine.com/news/10/6/11

BUSINESS

Osram Sylvania and Comcast partner on adaptive home lighting

Osram Sylvania and cable company Comcast have partnered to offer Comcast subscribers wireless controllable lighting. Osram Sylvania demonstrated the Ulta iQ BR30 LED lamps at Lightfair in April 2013 with wireless controls based on the ZigBee Home Automation standard. Now the company is partnering with Comcast to offer the lamps to consumers that subscribe to Comcast's media services.

Comcast is primarily known as a cable company but also offers telephone services, and of late it has offered the Xfinity Home platform to customers for home security and automation, including remote con-

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Omni-Directional
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2700K CRI (RA)+80
Non-dimmable

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trol of devices such as the thermostat so customers can monitor and minimize energy usage. Now Comcast will add adaptive lighting to the service.

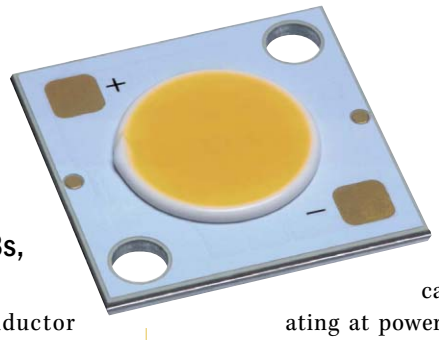
"With Osram Sylvania, we are bringing innovative lighting solutions that integrate with the Xfinity Home platform and provide home control and green technology features to our customers," said Mitch Bowling, senior vice president and general manager of new businesses for Comcast Cable. "Home automation is a growing trend that takes complex ideas and turns them into simple solutions that can be delivered to thousands of people. This is another example of how we are continuing to evolve our Xfinity Home product by creating more innovative home control solutions for our customers to enjoy."

The 11W Ultra iQ lamps target floodlight usages and deliver 700 lm at an efficacy of 63 lm/W. Comcast customers will be able to control the lamps with a smartphone or through the Xfinity gateway.

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

PACKAGED LEDS

TSMC announces new packaged LEDs and COBs, and China market plans



TSMC (Taiwan Semiconductor Manufacturing Company) SSL (Solid State Lighting) has announced new LEDs, which it displayed at the 2013 Guangzhou International Lighting Exhibition from June 9–12, 2013. A spokesperson confirmed with the new announcement that the company will be a merchant supplier and said that TSMC is already supplying some customers. The company also plans to open an office with business and technical staff in Shenzhen in the Guangdong province of China to better support lighting manufacturers in that region.

The new LEDs include the TH3 that is a single-die design set in a standard 3030 plastic package. The new chip-on-board (COB) LEDs include the TME, TMG, and TMH series that are increasingly larger in both package size and light-emitting surface (LES) area.

In a news release, TSMC said that the TH3 LED is capable of operating at power levels to 3W, although the company's website indicates a maximum 2W rating. The product is offered in CCT ranging from 2700K to 5700K with all but the highest CCT models having a minimum CRI of 80. At 350 mA binning current and 5700K, the LEDs offer efficacy ranging from 104–116 lm/W at 85°C and 25°C, respectively. At 2700K those numbers drop to 81–91 lm/W.

The TME, TMG, and TMH COB LEDs serve the ranges 10–18W, 20–30W, and 40–60W, respectively. TSMC said that the LEDs are compatible with the footprints required for use in Zhaga modules. The efficacy is in the same ranges as the single-emitter LEDs, and the COBs are rated at either 29V or 38V forward voltage.

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

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FWHM 12° 24° 38°
LED For
CREE CXA15xx/25xx
CITIZEN CLL030/CLL040
NICHIA 110

Holder
LL01A00SUKB2
WxH(mm)
Φ37.6 x 6

LL01SP-ATHxxR49

DxH(mm) 75 x 40
FWHM 15° 24° 38°
LED For
CREE CXA25xx
CITIZEN CLL030
SHARP Mega Zenigata (15~50W)

LL01CT-APGxxL06

DxH(mm) 84.6x 18
FWHM 24° 38°
LED For
CREE CXA2530
CITIZEN CLL030
NICHIA 110
SHARP GW5BMR10~12W
GW5DLA15W
GW5DLC25W

Connector
LL01CRRY15H2
DxWxH(mm)
40.45x47x4.45

Upper part

Lower part

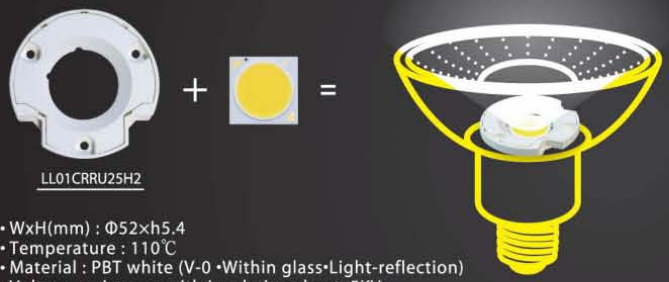
LL01CR-AYMxxR14-P

DxH(mm) 90 x 50
FWHM 15° 24° 38°
LED For
CREE CXA25xx
CITIZEN CLL030

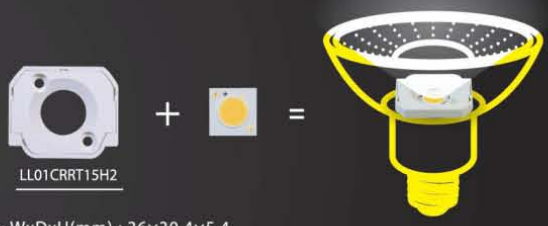
LL01CT-AOFxxL06

DxH(mm) 74.4 x 13
FWHM 24° 38°
LED For
CREE CXA1512
CITIZEN CLL020
NICHIA 110
SHARP GW5BMR10~12W
GW5DLA15W
GW5DLC25W

Connector



- WxH(mm) : Φ52×h5.4
- Temperature : 110℃
- Material : PBT white (V-0 •Within glass•Light-reflection)
- Voltage resistance with insulation sheet: 5KV
- To take pay Bldg su : M3 × 3 Up
- Suitable for wire : · Non-consolidated line Φ0.8, Φ1.0
  · For solder-dipped stranded 0.5㎟ · AWG20



- WxDxH(mm) : 36×30.4×5.4
- Temperature : 110℃
- Material : PBT white (V-0 •Within glass•Light-reflection)
- Voltage resistance with insulation sheet: 5KV
- To take pay Bldg su : M3 × 2 Up
- Suitable for wire : · Non-consolidated line Φ0.8, Φ1.0
  · For solder-dipped stranded0.5㎟ · AWG20

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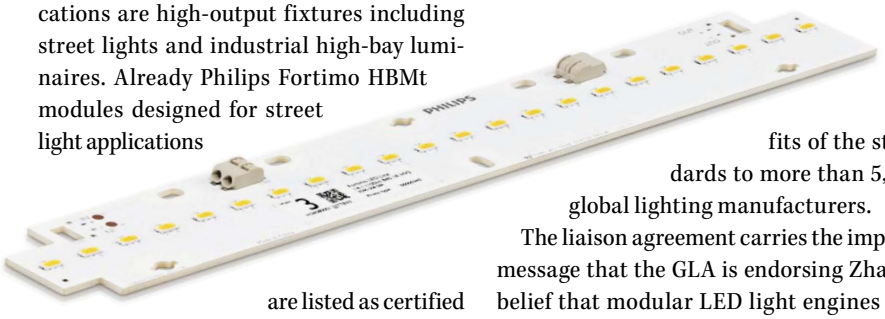
funding + programs

Zhaga expands certification program, adds GLA liaison

The Zhaga Consortium has authorized three test organizations to issue certifications for solid-state lighting (SSL) products that meet Books 4, 7, and 8, thereby formally starting the certification process for those specifications. The organization also signed a liaison agreement with the Global Lighting Association (GLA).

Zhaga calls its specifications for modular light engines Books, and the industry coalition continues to expand the applications covered by the specifications. Book 4 covers a non-socketable light engine with separate control gear or driver. The intended applications are high-output fixtures including street lights and industrial high-bay luminaires. Already Philips Fortimo HBMt modules designed for street light applications are listed as certified on the Zhaga website.



Book 7 targets applications such as office lighting and defines a non-socketable light engine with separate driver. Modules such as the certified Philips LED Line series (pictured) would typically find use in ceiling troffers.

Book 8 defines a socketable light engine with integrated driver for applications such as downlights. The term socketable implies a light engine that can be replaced or installed in a fixture without tools.

Zhaga announced that Dekra, UL, and VDE are authorized to issue test reports on the new specifications. Zhaga said the full specifications will be published on the organization's website soon. The organization had previously published Books 2 and 3. Certification testing for Books 5 and 6 should come soon.

The liaison agreement with the GLA could help accelerate adoption of the modular Zhaga approach to SSL. The GLA is chartered to promote sustainable energy-efficient lighting and is a top-level organization that includes leading national and regional lighting industry associations in Europe and elsewhere. The partnership will entail Zhaga regularly updating the GLA on Zhaga activities so the GLA can communicate the benefits of the standards to more than 5,000 global lighting manufacturers.

The liaison agreement carries the implicit message that the GLA is endorsing Zhaga's belief that modular LED light engines can lower R&D costs for lighting manufacturers and provide a broader choice among interchangeable products from multiple vendors. For Zhaga, the agreement will provide a conduit for it to spread its message. "The lighting industry operates on a global scale, and the specifications being developed by Zhaga are for global use," said Menno Treffers, secretary-general of the Zhaga Consortium. "It is very important for Zhaga to be able to share the results of its work throughout the international lighting community, and the liaison with GLA provides a clear route to achieve this goal." ◄

MORE: ledsmagazine.com/news/10/6/12

USDA and SETi document UV LED benefits for fresh produce

Sensor Electronic Technology Inc. (SETi) has announced the results of a three-year research program, conducted with the US Department of Agriculture (USDA), that prove ultraviolet (UV) LED lighting is an effective technique in extending the shelf life of produce. Strawberries in a refrigerator that were continuously lit with LEDs in the 280–315-nm UVB wavelength range exhibited no mold or decay after nine days.

"Findings of this exciting program are expected to have a major impact on the appliance business to extend the shelf life and preserve nutritional value of the fresh produce," said Remis Gaska, president and CEO of SETi. UV LEDs are an especially good match for application inside refrigerators, according to SETi. Because LEDs can be turned on and off instantly, appliance makers could design a refrigerator in which the UV lighting is turned on only when the door is closed.

The energy efficiency of LEDs means that a refrigerator equipped with such lighting would use little additional energy. The research project used only 20 mW/m^2 of power. Gaska added, "We look forward to the prospect of UV LEDs in residential refrigerators impacting everyday life and reducing waste through spoilage."

The researchers placed eight tubs of strawberries in a chiller cabinet set to 5.4°C (41.72°F) and humidity between 94–98%. Two tubs were left in the dark. In the other six tubs, the team mounted a single LED in the top cover of each tub — testing LEDs over different wavelengths and power levels.

Strawberries in the unlit tubs exhibited mold and decay after three to four days. Strawberries lit with UVC (100–280-nm) LEDs were mold free after nine days but showed some sign of decay. The fruit lit with UVB LEDs was mold and decay free after nine days.

MORE: ledsmagazine.com/news/10/5/14

funding + programs

DOE awards $10.1 million in new research awards

As a response to the SSL Manufacturing R&D funding opportunity announcement made in December 2012, the US Department of Energy (DOE) has competitively selected five solid-state lighting (SSL) projects to receive the fourth round of funding. The two-year projects will focus on reducing costs while maintaining quality by improving the quality and performance of LEDs and OLEDs. Total DOE funding for the five projects is $10.1 million, while the five companies will put in a matching $10.1 million investment.

"This partnership with industry to produce affordable, efficient lighting will save consumers money and create American jobs," said DOE Secretary Ernest Moniz. "It's another example of how energy efficiency is a win-win proposition for our economy."

Cree Inc., Durham, NC, with a $2.3 million DOE investment, will develop a modular design for LED lights that can link together multiple units to fit larger areas.

Eaton Corp., Menomonee Falls, WI, with a $2.4 million DOE investment, will develop an innovative manufacturing process that streamlines LED fixture design and removes unnecessary materials and parts.

OLEDWorks, LLC, Rochester, NY, with a $1 million DOE investment, will develop and demonstrate new spray printing equipment that reduces overall manufacturing costs in OLEDs and may support cost-competitive mass production.

Philips Lumileds, San Jose, CA, with a $1.8 million DOE investment, will develop an alternative to the standard flip-chip device that grows an LED face-down on the sapphire substrate.

PPG Industries, Inc., Pittsburgh, PA, with a $2.3 million investment, will develop a cost-effective OLED manufacturing process to help commercialize an integrated substrate that includes the glass foundation and other necessary layers. ◄

MORE: ledsmagazine.com/news/10/6/5

MSSLC will host annual meeting in September

The DOE has announced that its Municipal Solid-State Street Lighting Consortium (MSSLC) will hold its annual meeting in Phoenix on September 11, 2013, scheduled coincident with the Street and Area Lighting Conference (SALC). The meeting will be open to consortium members, although the agency will also allow others to register including government and utility staff that work on street light projects, lighting designers and consultants, and finance and budget professionals such as from energy services companies.

Attendees will hear directly from US cities that have already undertaken LED street light projects. Presentations will include information on funding options, especially in today's climate with much of the funding from the American Recovery and Reinvestment » page 21

funding + programs

EPA and Soraa spar on lamp efficacy

Soraa continues to lobby the EPA to level the playing field in Energy Star efficacy requirements for LED retrofit lamps. Previously, the company had asked for a reduction of 5–10 lm/W in lamps with a CRI of 90 or above. The company first made the request along with researchers, utilities, and a prominent lighting designer back in January 2013 (ledsmagazine.com/news/10/1/16).

Recently, the group again went public with a plea in response to the fact that the EPA did not act on the prior request in the latest draft of the Energy Star lamps specification (ledsmagazine.com/features/10/5/8). The group is now asking the EPA to require lamps in the 80–90 CRI range to deliver a 5-lm/W higher efficacy specification than lamps with CRI above 90, in recognition of the fact that higher CRI is known to result in lower efficacy.

Soraa and the other petitioners are concerned because Energy Star recognition is essentially a de facto requirement for customers seeking rebates or incentives for investing in energy-efficient lighting upgrades. The group in general believes that if the efficacy requirements are left unchanged, the lighting industry will generally deliver lower-CRI lamps that more easily meet the current efficacy requirements. Soraa believes that adding a second CRI tier would provide buyers a fairer choice of higher efficacy or higher CRI.

Soraa and the loosely formed coalition believe that lower-CRI lamps will lead to poor buyer experiences and a slowdown in the adoption of LED lighting much like what occurred with compact fluorescent lamps (CFLs). They had argued that a slight reduction in efficacy requirements could actually broaden adoption of high-quality products and boost aggregate energy savings. Now they are simply asking for what they consider a level playing field for higher-quality lamps.

The EPA has said that it would still welcome comments on the efficacy issue. But with the release of the latest draft it also said there were plenty of high-CRI products on the market that met the requirements. ◄

MORE: ledsmagazine.com/features/10/5/8

» page 18

Act having been used.

The morning half of the MSSLC meeting will be open to all SALC delegates as part of the conference program or to attendees that register just for the MSSLC meeting. The afternoon session will only be open to participants that register specifically for the MSSLC meeting. Lighting manufacturers, distributors, and representatives will not be allowed to register for the MSSLC meeting. Get more details at the DOE SSL website: www1.eere.energy.gov/buildings/ssl/events_detail.html?event_id=7999. ◄

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Conference will include LED technology and standards updates

MAURY WRIGHT previews conference sessions and projects that a lively debate will take place on LED component trends, and that standards and regulatory discussions will prove very informative to SSL industry players.

The LED Show, scheduled for August 13–15, 2013, in Las Vegas, NV, will offer an inside look at the solid-state lighting (SSL) industry starting from the LED component level and covering elements of indoor and outdoor lighting systems and design guidelines. The sessions on the latest in LED components should be lively as the speakers come from companies with significantly different viewpoints on where components for SSL are headed. A session on industry regulatory and standards issues will be a must-see with the ongoing changes in that landscape. There will be plenty more to learn in the sessions, and what is expected to be the busiest exhibit floor yet for the event.

A pre-conference workshop, conference sessions, and exhibits are the cornerstones of The LED Show. The workshop will take place on August 13 and will focus on SSL retrofits. Leading lighting designers will present and a panel discussion will include lighting consultants and executives from lighting manufacturers. See the full list on the conference website (theledshow.com/conference.html). The main sessions and exhibits will take place over two packed days, August 14–15.

LED component update

Kicking off the conference sessions on Wednesday morning, executives from Philips Lumileds, Nichia, and Cree will discuss the latest advancements in LED chips. The session will be compelling for both SSL product developers and lighting specifiers who need to understand the light-source technology in finished lamps and fixtures.

The LED component segment is rapidly evolving, yet the jury is out as to which advancements will have the greatest impact on the lighting industry. And that area of uncertainty is what will make the session especially interesting because the participants surely have different agendas.

Paul Scheidt, product marketing manager at Cree, plans to discuss the component trends that Cree believes have staying power. For instance, Scheidt said that traditional high-power LEDs that operate at low voltage and high current have been the only technology proven consistently successful in the SSL industry. Scheidt said, "There is always a new technology trend that's considered the magic bullet to enable mass LED adoption."

When pressed, Scheidt said examples of trends include remote phosphor, AC LEDs, and mid-power LEDs. Many are used but often in limited volume relative to mainstream high-power LEDs. He added that multi-emitter, high-voltage, low-current LEDs are an example of one trend that might have lasting value.

The mid-power trend is an especially hot one right now; however, will it have staying power? Scheidt said, "I see the long-term reliability of those parts being their disadvantage." Cree has announced mid-power LEDs recently (Fig. 1) but is using what it believes is a more reliable ceramic package relative to the lower-cost plastic packages used by most vendors (ledsmagazine.com/news/10/5/13).

Plastic packages

Nichia will clearly take issue with that line of thinking. The company has been at the forefront of the movement to use low- and mid-power LEDs in general lighting products. The company offering the Nichia 757 LED (Fig. 2) in a plastic package has led the industry in reducing component costs. At Strategies in Light earlier this year, Strategies Unlimited analyst Ella Shum said that Nichia drove component prices under $2/klm [dollars per kilo lumen — a benchmark figure tracked by the US Department of Energy (DOE)] by the end of 2012. In contrast, the average price for LEDs in 2012 was $3.45/klm, and high-end, high-power LEDs certainly sell for more.

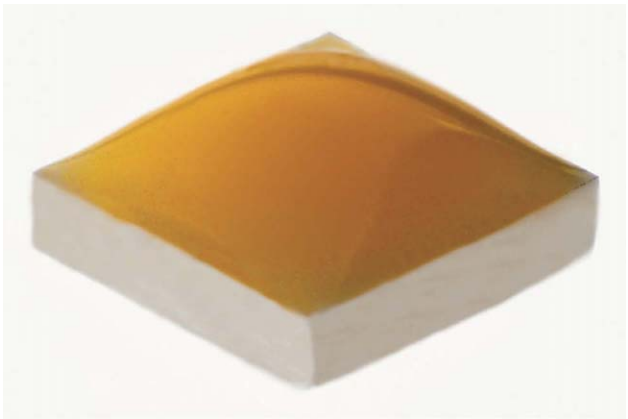

FIG. 1. Cree is focused on what it believes are more reliable ceramic packages for mid-power-class LEDs.

Erik Swenson, manager of LED sales at Nichia, said LED component pricing remains the largest barrier to broader LED adoption. Nichia, and others with low- and mid-power LEDs, leverages the scale and manufacturing expertise it has gained in manufacturing plastic-packaged LEDs for the TV and display backlighting industry that has by far consumed the most white, phosphor-converted LEDs of any application segment to date.

Swenson said that Nichia has brought "superior luminous density and quality" to plastic packages for general lighting. He added that the SSL industry is coming full circle, returning to lower-power LEDs, and that the industry should be "dancing with the one that brought ya," presumably implying both the leadership position Nichia has in global LED sales and the fact that the low-power LEDs were the first truly high-volume market for LED manufacturers.

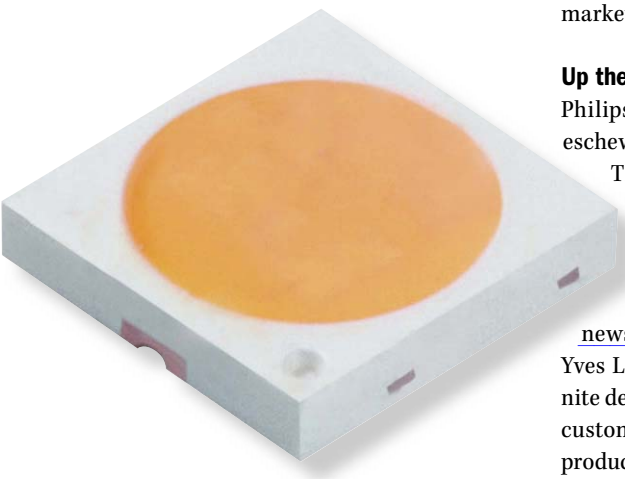

FIG. 2. The Nichia 757 LED comes in a low-cost plastic package but the company says it delivers lighting-class performance.

Up the food chain

Philips Lumileds, meanwhile, will likely eschew the debate over mid-power LEDs. The company has ramped its participation in mid-power LEDs (Fig. 3) recently and even introduced its first low-power LEDs for the lighting market (ledsmagazine.com/news/10/5/5). At Lightfair, CEO Pierre Yves Lesaicherre said that there is a definite demand for mid-power devices among customers. He said that the devices could produce good beam spreads and can serve cost-sensitive markets and applications, while also insisting that high-power LEDs have a very bright future.

Chad Stalker, regional marketing manager for the Americas at Lumileds, will present at The LED Show. Stalker said he will focus on one of the questions that he hears most often from customers: "Can LEDs continue to improve at the rate that they are now?" The answer will likely be yes, but the improvements may take place beyond the individual component level.

FIG. 3. Philips Lumileds expanded its 3535 mid-power family in May.

Stalker said that LED manufacturers must perform a balancing act, using as many

of the LED die from a production run as possible to minimize component cost while meeting performance expectations that are most easily satisfied by only selling what he called the "upper bins." The answer may lie in a move to more sub-assemblies or modules that combine LEDs across the production run and that deliver performance and efficacy without high cost.

Standards and regulations

Meanwhile, another session that will have broad applicability across both the product-developer and lighting-specifier spaces is entitled "SSL standards & certifications." Speakers from CSA, UL, and TUV SUD will participate. The topic area is critical because assurance of SSL product safety and performance is rooted in such specifications. Moreover, programs such as Energy Star are critical in the mass adoption of LED-based lighting.

FIG. 4. Marci Sanders of D&R International will address the DOE Lighting Facts program at The LED Show.

One program that is critical to success for SSL products is the DesignLights Consortium (DLC) Qualified Products List. Utilities and others use that list almost as an approved vendors and products list.

Jason Chesley, sales manager for energy efficiency at certification body TUV, will cover the DLC program in detail because he said, "DLC is the hottest program out there for rebates on commercial SSL projects." Chesley said that D&R International, a consultancy that runs multiple lighting industry programs such as the DOE Lighting Facts Label program, has done an excellent job administering the program. He said, "The DLC model is what every energy-efficiency program around the world should strive to emulate." Note that Marci Sanders of D&R will also present an update on Lighting Facts in a different session at the show (Fig. 4).

Attendees won't solely learn about US programs, either. For example, Glen Tubrett, director at CSA Group, will discuss both Canadian standards for SSL and the need for manufacturers to have a global outlook on regulatory and standards issues. In particular, Tubrett said he will discuss ongoing work in Canada to harmonize standards with the UL standards in the US. But he will also discuss IEC standards that are promulgated in Europe and the trend toward globalizing the function of certification bodies.

One set of standards being driven by the lighting industry, the Zhaga Consortium books for interchangeable modular LED light engines, has a decidedly global scope. UL will address the progress of Zhaga in its presentation. UL recently announced that it has been certified to perform testing to Books 4, 7, and 8 (ledsmagazine.com/news/10/6/12).

The LED Show exhibits

Attendees will clearly have an outstanding educational opportunity in the conference at The LED Show. Indeed, we've covered a small segment of the two-day program. Still, the exhibits will prove equally valuable to attendees. As we went to press, the exhibitor count was approaching 90 with representation from every major region around the world.

The event will also include plenty of networking opportunities for industry professionals. There will be delegate lunches and coffee breaks in the exhibit area. Moreover, a networking evening reception will be the hot spot in Vegas on Wednesday evening once the sessions end.

lighting | **ADAPTIVE CONTROLS**

Matching SSL and control technology remains a challenge

ETHAN BIERY explores the state of the industry for LED dimming and control and recommends the paths for success to lighting specifiers.

The rapid adoption of LED light sources is rooted in energy savings, long life, and new fixture options that enable them to be used in almost any application. They are highly efficient; deliver a useful lifetime averaging 50,000 hours; and offer very good color rendering. LED lamps also emit very little infrared (IR) radiation and contain no mercury. Despite these clear advantages, issues of compatibility between LED lamps, drivers, and controls continue to cause confusion for specifiers and their customers. If they are paired improperly, performance will suffer.

The best strategy for selecting an LED product is a holistic approach that takes into consideration a variety of factors including the application type, required dimming performance, and control requirements. Mock-up installations and expensive, time-consuming testing may be necessary before customers are confident that the proposed lighting system is the best choice. Many LED component and control manufacturers are investing more time and effort into dimming testing and research, and can provide compatibility information to ensure successful LED lamp, driver, and control installation.

Looking beyond baseline efficiency

LEDs are energy efficient by design. Simply using LED lamps or fixtures can help a facility meet updated building and energy codes while reducing electricity consumption and cost. So why worry about dimming your LEDs? For the same reason you control any light source: to maximize energy savings, extend system life, enhance flexibility, increase productivity, and provide a safe, comfortable environment for building occupants. Additionally, many energy-efficiency standards are being updated to mandate more sophisticated lighting control strategies, effectively mandating dimming in many applications.

A wide range of controls are available — from a single switch or dimmer to a centralized lighting control system — to provide maximum flexibility, as well as measurement and reporting tools to help you effectively analyze the energy savings being achieved with the lighting and control installation. Sophisticated, configurable systems can allow tuning of spaces based on actual occupant usage post-installation, which over time can allow lower energy densities that surpass design goals. Furthermore, easy-to-install wireless controls facilitate simple retrofits, reducing installation and programming costs, and improving return on investment (ROI).

Regardless of the control system you choose, it is critical to work with a manufacturer who can guarantee compatibility and performance with the desired LED loads, eliminating many of the common concerns and issues that are seen with LED installations. Let's discuss why and how to implement dimming in more detail.

Maximize savings and system life

Dimming LEDs saves energy at a roughly 1:1 ratio, which matches or even exceeds the energy reduction of dimming fluorescents. This means that if you dim LEDs down to 50% of their light output you save nearly 50% of the associated energy use (Fig. 1). While it is true that LEDs are already very efficient compared to almost any other light source, you save even more energy by dimming them.

Dimming LEDs also makes them run cooler, extending the life of the electronic components in the driver, as well as the phosphor in the LEDs. This will potentially double or triple the useful life of the LED lamp or module. Research is ongoing to better quantify the relationship of dimming LEDs and lifetime extension.

Still, you must choose the fixture, driver, and control combination to meet project needs. LEDs are making great strides, and LED products now exist for replacing virtually any fixture type including general-purpose lighting, downlights, cove lights, and outdoor lighting. The type of control you choose will depend on the results you want to achieve. For example, in a lobby or atrium, a 20% minimum dimmed light level is typically acceptable. But in a conference room or restaurant, very low levels of light — dimmed down to 1% — are often desirable.

It is all too easy to neglect the importance of LED dimming range. While 10% dimming may sound appropriate for most applications,

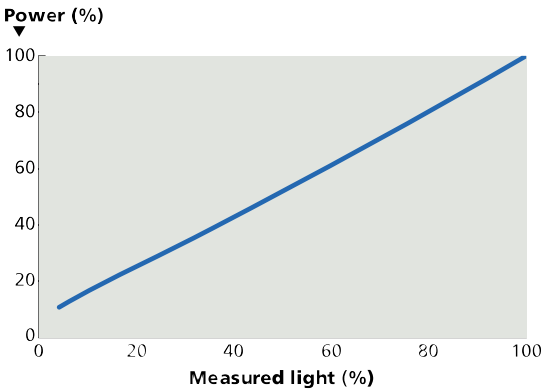

FIG. 1. There is a linear relationship for dimming level and consumed power with LED lighting.

ETHAN BIERY *is the LED engineering leader at Lutron Electronics Co., Inc.*

our eyes are sometimes too smart for their own good. Due to the dilation of the pupil in the human eye, lower light levels are perceived as brighter than expected. For example, a 10% light level appears to be about 33%. Even 1% dimming is perceived as a 10% light level (Fig. 2).

The expected dimming range should always be part of the product specification, but it is not always provided by the manufacturer. Furthermore, even for a given LED load, the dimming range may vary depending on the control used. Designers and specifiers need to be aware of the low-end light level that can be achieved with the proposed LED load and control combination.

If all the parts and pieces are not carefully evaluated, the result can be dimmable products that do not work as claimed. For example, you can end up with lights that never turn off completely, or that flicker, pop on, or drop out, leaving the end user with the perception that dimming LEDs does not always work.

Challenges of dimming

It is generally recognized that LEDs are inherently dimmable and controllable, so why are there so many challenges with dimming them? It is the result of the physical differences between LEDs and their predecessors including incandescent and halogen lamps.

Incandescent lamps create light by heating a tungsten wire to high temperatures in a low-pressure glass envelope, causing it to glow white hot. Electrically speaking, these are very simple devices — the more voltage delivered to the source, the hotter it got, and the more light it produced. With legacy sources the shape of the voltage waveform really didn't matter. AC, DC, phase cut, or nearly any other form would provide the same amount of light for the same RMS voltage.

LEDs behave very differently. Light is produced by subatomic processes in specially designed semiconductor materials. For a given LED device, the amount of light generated is proportional to the amount of current (not voltage) passed through the device. Furthermore, the current can flow in only one direction through an LED, meaning they can only tolerate DC current. (Note that so-called AC LEDs rely on tricks such as two diodes that are wired such that current flows through some diodes in one direction, and other diodes in the other direction.) Finally, LEDs are inherently low-voltage devices, typically requiring a large reduction in voltage from the mains wiring. These functions — reducing the voltage, regulating it to DC, and controlling the current — are all handled by a device called an LED driver.

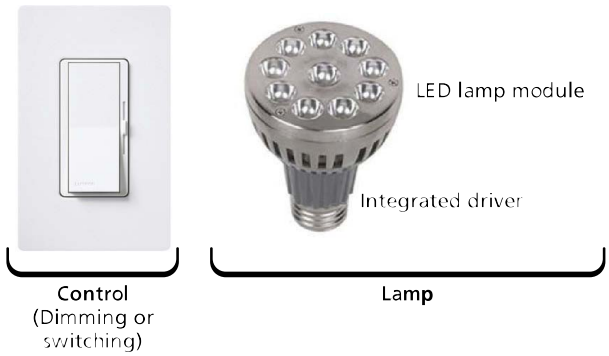

FIG. 3. LED lamps have integral drivers that limit control options.

LED drivers come in a variety of designs, constructions, and feature sets. One thing they have in common is that they do not have the same electrical properties as an incandescent load, and this difference is essentially the root cause of compatibility challenges between controls and LEDs.

Different manufacturers' drivers prioritize different requirements. Some may optimize for cost, some for size, some for lifetime, and so on. Part of the design of the driver determines how well, and how low, it will dim, and using what controls. This fact leads to two important conclusions:

The design of the driver determines the best possible dimming performance that can be achieved.

The compatibility of the driver with the control determines how well the driver will achieve this performance.

In essence, even the best control cannot make an LED lamp dim beyond its design parameters. Both poor driver design and improper pairing with a control can lead to undesired aesthetic performance, including flicker, drop-out, dead travel, or acoustic noise (buzzing).

Additionally, poor driver design and control pairing can lead to reduced lifetime of the control or load. A good driver will guarantee smooth, continuous dimming to very low light levels on a wide variety of controls with no negative impact on lifetime, matching the dimming performance that people expect from incandescent lamps. Few driver manufacturers in the industry today can reliably make this claim.

Ensuring expected performance

In order to properly align customer expectations with LED system performance, several

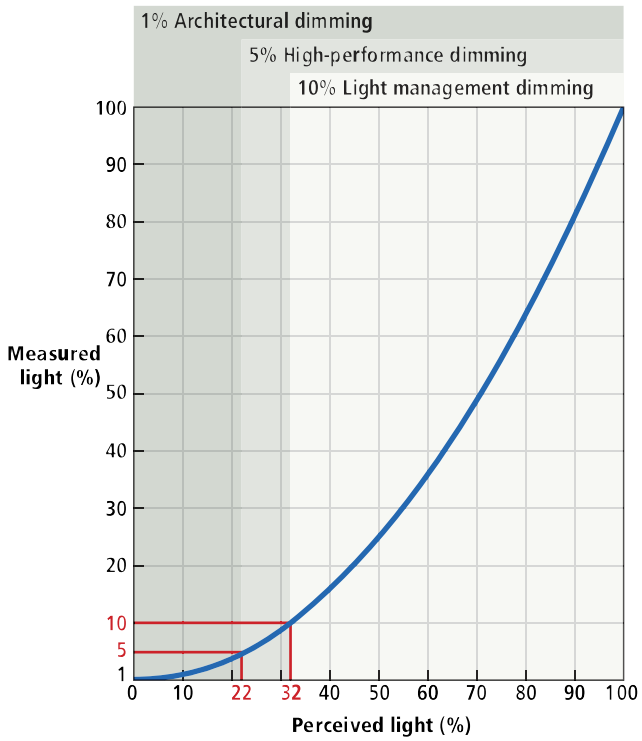

FIG. 2. The human eye perceives much higher light levels than the actual output from dimmed sources.

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Aluminum extrusions make the difference.

Thanks to a higher level of thermal conductivity, aluminum extrusions can be as much as 53% more efficient than aluminum castings. In addition, Sapa has developed a new method of manufacturing high ratio air cooled heat sinks. Utilizing our experience in aluminum extrusion combined with Friction Stir Welding technology we're able to achieve heat sink ratios in excess of 40:1. Our new technique utilizes a modular concept allowing for maximum flexibility in fin geometry, fin ratio, and heat sink footprint. It also allows for the production of large scale heat sinks up to 20" width.

With complete thermal engineering and design assistance plus full fabrication capabilities at multiple locations across North America, Sapa can provide finished component heat sinks for all your needs.

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factors need to be considered during the course of designing an LED project:

- the load type (retrofit lamp or fixture)
- the required control type
- the number of loads allowed on a control
- the dimming performance of the load and control combination

For assistance, look for trusted manufacturer resources that can assist you with the selection process, such as the LED Control Center of Excellence offered by Lutron Electronics. Let's discuss the factors in more detail.

LED light sources come in two basic types: retrofit lamps (sometimes called screw-in lamps or LED lamps), and LED fixtures (Figs. 3 and 4). Different applications call for different solutions, but from the perspective of dimming compatibility, there is one major distinction. LED retrofit lamps have a fixed driver built into the lamp that can only be controlled via phase-cut dimming, while LED fixtures can offer a selection of drivers, available at specification time, which may provide a range of dimming performance and compatible controls.

If retrofit lamps are being used, even a proven lamp and control combination will max out performance at the lamp's published capability. Improved performance may require selection of a different lamp, perhaps from a different manufacturer. With fixtures, most manufacturers offer a range of drivers, which allows selection of the dimming performance in advance, without affecting the aesthetic or optic performance of the fixture.

For general-purpose illumination, there are four predominant control methods available:

- forward-phase control
- reverse-phase control
- 0–10V analog control
- digital control (DALI or EcoSystem)

Each of these methods has strengths and weaknesses, making some more suitable for certain applications than others. However, lighting designers and specifiers often select a fixture or control system without a full understanding of the ramifications of that selection when it comes to LED and control compatibility. Note that while other control schemes exist, including DMX or direct wireless control to lamps or fixtures, these methods are not widely used in today's general-purpose lighting applications.

Forward phase

By far the most commonly used dimmer today, forward-phase controls are dominant around the world and 150 million are estimated to exist in North America alone. Thus, many LED loads claim compatibility with forward-phase dimmers. Forward-phase dimmers cut, or turn off, the front part of the 60 Hz, 120V (in North America) mains voltage sine wave (Fig. 5). The cut supply effectively reduces the RMS voltage delivered to the fixture. The more of the sine wave that is cut off, the lower the voltage, and the less energy the load uses. This method is extremely common because it is easy, generally inexpensive, and uses the

existing wiring to the fixture.

The recently released NEMA SSL7-A standard helps define the proper behavior of forward-phase dimmers and LED loads to ensure reliable operation; it also provides a basic expectation of performance. LED loads and controls marked as SSL7 compliant should remove much of the guesswork associated with compatibility for this control type.

Reverse phase

Reverse-phase dimmers operate much the same way as forward-phase dimmers do. They reduce the RMS voltage going to the load by cutting off part of the sine wave. However, unlike forward-phase dimmers that remove the front part of the sine wave, reverse-phase dimmers remove the back portion of the sine wave (Fig. 6). Like forward-phase dimmers, this reduces the RMS voltage to the fixture and uses the existing wiring.

This method was originally developed for control of electronic low voltage (ELV) transformers with low-voltage halogen lamps. These loads make up a much smaller portion of the market than their line-voltage counterparts. Therefore, reverse-phase dimmers are much less common than forward-phase dimmers. Only a small percentage of installed dimmers are compatible with ELV loads. However, due to the electrical similarities between ELV transformers and LED drivers, several driver manufacturers design their drivers to work exclusively with reverse-phase dimmers.

Analog 0–10V control

In contrast to the previous methods that rely strictly on existing wiring, the analog 0–10V scheme requires an additional pair of low-voltage wires to be run from the control to each fixture. This low-voltage pair provides the signal to the driver, which determines the target light level. A voltage of 1V tells the driver to go to the low end of its dimming range, while a voltage of 10V tells the driver to go to the high end. Generally, a line voltage switch is also included in the system to cut mains power to the driver when the lights should be off. This behavior is specified in an IEC standard, 60929, which covers only very basic functionality. For example, there is no assurance provided by the standard that smooth, continuous dimming to low light levels will occur. Mixing 0–10V fixtures from different manufacturers or using long wire runs for the 0–10V signal can cause noticeable differences in light levels across multiple fixtures.

While 0–10V allows the control wires to be run separately from the power wires, it has an inherent disadvantage when multiple control strategies are desired. By definition, all fixtures tied to the same pair of 0–10V wires are controlled together and will dim together. This fact means that for spaces with multiple control types, where fixtures must dim to different levels due to differing control inputs (such as daylight sensors, personal zone controls, and occupancy sensors), the room must be broken into multiple areas of control, each with their own 0–10V wires. Control of 0–10V loads can become very complex to design and install for all but the simplest applications. One other disadvantage of 0–10V is that any change of functionality or fixture zoning requires rewiring of the 0–10V control links.

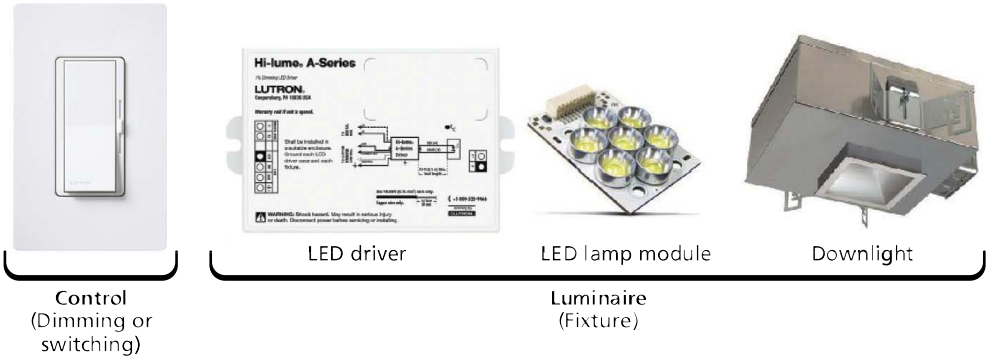

FIG. 4. Luminaires often allow the specifier to choose a driver with the desired adaptive controls.

Digital control

Like 0–10V, digital control methods, such as Lutron's EcoSystem and the Digital Addressable Lighting Interface (DALI), require an additional pair of low-voltage wires to be run to each fixture. Unlike 0–10V, however, the pair of wires sends bi-directional communication signals to each fixture, allowing individual addressability and control. DALI, a commonly used digital protocol, is also defined by the IEC, but differing interpretations of the standard can lead to incompatibilities between devices from different manufacturers even if they all claim DALI compliance. EcoSystem was developed by Lutron based on DALI and compatible fixtures are offered by Lutron and other lighting companies such as Cree and GE Lighting. Compatible fixtures provide guaranteed control compatibility, no matter which manufacturer is selected.

Digital control methods allow easy layering of control schemes. Each fixture can behave independently from all others if that is desired to achieve lighting goals. Digital technologies enable advanced functionality and zoning of fixtures through a simple software interface, with no modification of the wiring required. Digital controls allow flexibility in space configuration and reuse. Digital fixture control most effectively unlocks the capability of smart lighting promised by LEDs.

Control ratings

As was described previously, LED loads do not electrically behave like incandescent loads, leading to differing performance on different controls. However, beyond aesthetic performance, the electrical characteristics of many LED loads cause additional stresses on controls, beyond what their wattage alone may indicate. This complicates determining how many loads — for instance, how many retrofit lamps or downlights — can be reliably connected to a control.

The high inrush currents, repetitive peak currents, and RMS currents that can occur when phase-cut dimmers are used with LEDs means that most controls rated for incandescent loads cannot handle nearly the same wattage of LED loads. Generally, only detailed electrical testing can determine the proper minimum and maximum number of loads that can be connected to a control.

What many users do not understand is the effect of the lamp selection on the regulatory rating of the control. Controls are tested and listed with a specific load type in mind. For example, UL may rate a control as appropriate for incandescent or magnetic low voltage (MLV) loads. Using them on other load types, such as ELV loads even at the same voltage level, means they are being used beyond their original design and testing, which can lead to unexpected behavior or decreased reliability.

Most existing incandescent dimmers have not been designed, rated, or tested by UL or another nationally recognized testing laboratory (NRTL) with LED loads. Fortunately, many control manufacturers have recently released dimmers explicitly rated for controlling LEDs, such as the C·L dimmer family from Lutron Electronics. These types of controls have LED-specific ratings, allowing the actual wattage of the LED to be used to determine the maximum loading. In summary, the manufacturer of the control should always be consulted to determine whether or not the control in question has been tested on LEDs, and that the control is not overloaded.

A holistic approach to LED control can help meet and exceed customer expectations. Technologies are improving; control options, available literature, and general knowledge are expanding; and LEDs can now be effectively used in virtually any type of commercial application. By choosing the right manufacturer, control, and driver, and considering key issues, it will be easier than ever to provide customers with LED lighting and a control system that meets energy-saving, performance, and aesthetic expectations.

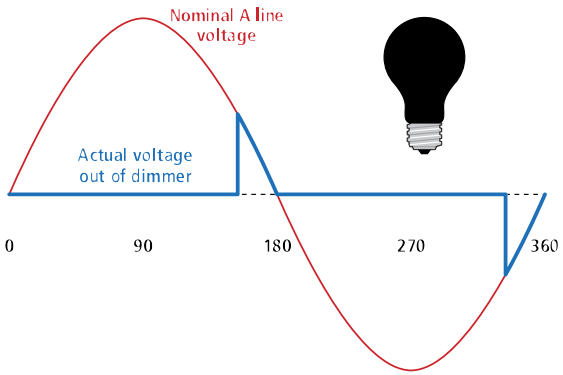

FIG. 5. Forward phase-cut dimmers eliminate the voltage during the initial part of each half cycle of the AC line.

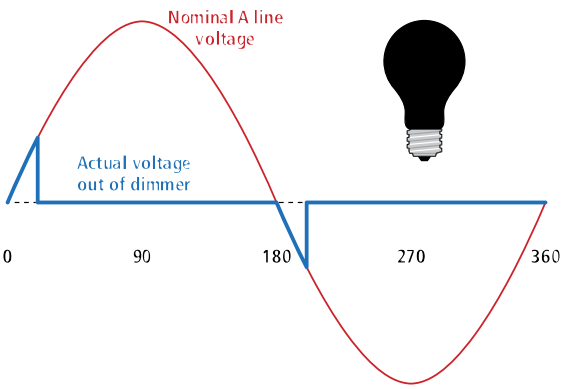

FIG. 6. Reverse phase-cut dimmers cut the voltage at the end of each half cycle.

regulations | EUROPEAN STANDARDS

Standards emerge specifically for SSL test methods

European standards, driven primarily by the IEC, increasingly address safety and performance issues that are specific to LED-based lighting, explains **PASI ORREVETELAINEN**.

In recent years, a large variety of LED-based solid-state lighting (SSL) products has emerged on the market. LEDs have now realized their full potential for everyday illumination, rather than being limited to specialty applications. The ever-increasing number of LED products particularly represents a challenge to test laboratories, whose task it is to check for product safety. Generally, safety testing is carried out by testing products against relevant product standards. However, when new technologies such as SSL emerge, no specific product standards exist and so only related standards can be applied. Fortunately, this situation has now markedly improved in the LED field around the globe; we will discuss the regulatory landscape in Europe.

The standards for LED lighting products can be roughly divided into two groups: safety and performance. As the terms imply, the first group is mainly concerned with the safety issues related to products, while the latter focuses on the performance of the products. Some overlaps occur in the standards, because some requirements may be safety oriented but are located in the performance standard and vice versa.

In Europe, the safety of the lighting product has to be ensured according to the Low Voltage Directive 2006/95/EC. In the Low Voltage Directive, the application of performance standards is not mandatory, because they do not affect the safety of the product. Performance standards specify requirements for how to test the performance characteristics of products. Most of the tests included in performance standards verify properties claimed by the manufacturer. Less frequently, performance standards specify absolute requirements the product should fulfill.

PASI ORREVETELAINEN *is the project manager at SGS Fimko Ltd, Finland.*

LED lamps regulation

Due to an increasing interest in energy savings, LED lamps have become more and more commonly used as the preferred alternative to incandescent lamps. Until October 2012, it had therefore been an awkward situation in Europe, since there were no specific EN standards for LED lamps.

> The standards for LED lighting products can be roughly divided into two groups: safety and performance.

EN 62560, which now becomes the standard for self-ballasted, single-capped LED lamps, was only ratified in October 2012. Previously, combinations of other EN standards were applied to check the safety of products. However, the corresponding IEC 62560 standard has been valid since February 2011.

EN 62560 covers LED lamps that replace familiar mains voltage household lamps. As it is only intended for self-ballasted lamps, lamps with external control gear, or drivers, are not within the scope of the standard. Standards for such lamps are under development. The primary purpose of the standard is to ensure that the product is not and will not become unsafe during its lifetime in normal use. This goal also applies to cases where the lamp is damaged. The lamp must not impair safety even when the electronics inside the lamp fail. The standard also concentrates on the fact that the LED lamps will replace ordinary incandescent and compact fluorescent lamps and therefore should not have properties that impair the safety of the luminaires in which the lamps are installed.

The safety standard for double-capped LED lamps, which are intended to replace double-capped linear fluorescent lamps, is currently being developed. The primary concern for these lamps is their metallic surface. As metal conducts electricity, the safety distance from live parts, termed the creepage distance and clearances, is relatively large in order to ensure that any accessible metal parts do not become live with mains voltage under any circumstances.

Safety of luminaires

The EN 60598 standard series relates to the safety of luminaires. This series does not have special requirements for LEDs; instead the common requirements of luminaires have to be fulfilled by SSL luminaires. In addition, LED modules and control gear must comply with their own standards. Although this is not currently mentioned in the EN 60598 standard series, the safety of photo-biological radiation has to be assessed according to standard EN 62471. (For more information on photo-biological safety, see ledsmagazine.com/features/9/2/9.)

EN 62471 deals with safety aspects of radiation between 180 and 3000 nm, which includes ultraviolet (UV), visible, and infrared (IR) radiation. Ordinary LEDs intended for illumination do not radiate harmful UV

As LEDs do not need very high voltages to operate, it has become popular to provide an extra-low voltage to LED modules.

or IR, so only visible radiation is considered for LED luminaires and more specifically for the Blue Light Hazard (BLH). With its high energy content, blue light detrimentally affects the eyes. Therefore, luminaires have to be properly marked if the limits of safe radiation are exceeded.

The components related to the safety of the luminaire, either internal or external, have to further comply with their own safety standards.

LED modules and control gear

Usually, several LEDs are combined in SSL fixtures. The printed circuit board on which the LEDs are placed is often called an LED module or light engine. The safety standard for LED modules is EN 62031. LED modules can be self-ballasted, which means they have a driver or control gear integrated on the module. However, it is more common for the control gear, which supplies the LED module with its correct voltage and current, to be a separate unit. For a separate control gear, the standard EN 61347-2-13 applies. The EN 61347 series is intended for control gears and ballasts of various types of lamps. Parts 2-13 are intended specifically for the control gears of LED modules.

As LEDs do not need very high voltages to operate, it has become popular to provide an extra-low voltage (ELV), less than 25V RMS, to LED modules. Relying on ELV levels to the modules simplifies module safety assurance. If the voltage of the LED module is low enough, it is safe to touch the LED module with bare hands. However, this requires that the LED control gear is classified as safety extra-low voltage (SELV) or an SELV equivalent. The requirement for SELV is not only a low voltage, but the SELV circuit also must be separated from the mains supply by double or reinforced insulation. Thus, if an LED module claims to be SELV, it requires that the control gear is very safe as well.

Performance

LED products already have their own performance standards. Most of these standards are IEC/PAS, which indicates that they are Publicly Available Standards or pre-standards.

EN 62384 is the standard for LED control gear performance. As mentioned earlier, most of these requirements relate to the properties claimed by the manufacturer. However, besides an endurance test, there are requirements for abnormal conditions that the control gear has to withstand. During and after these tests, the control gear should function normally.

The IEC 62707 series is a family of performance standards intended for individual LEDs. The series is under development and the IEC has currently published one standard — IEC/PAS 62707-1 — concerning the color binning of white LEDs. Two additional parts of this standard

European standards cover safety and performance of SSL products.

	LED luminaires	LED control gears	LED modules	LED lamps	LEDs
Safety (LVD)	IEC/EN 60598 series --- EMF: IEC/EN 62493 (mandatory from 2/1/2013)	IEC/EN 61347-2-13	IEC/EN 62031	Self-ballasted: IEC 62560 (*EN 62560* ratified 10/15/2012) ad hoc standards: EN 60968 + EN 60061 + EN 62031 + EN 62471 Non-self-ballasted: *IEC 62663-1*	–
Performance	IEC/PAS 62722-1 IEC/PAS 62722-2-1 LED luminaires	IEC/EN 62384	IEC/PAS 62717	IEC/PAS 62612 Non-self-ballasted: *IEC 62663-2*	IEC/PAS 62707 series

Note: The standards in italics are under development or not approved to date. IEC/PAS standards are pre-standards.

will cover LED binning according to luminous flux and forward voltage.

The performance standards for self-ballasted LED lamps (IEC/PAS 62612), LED modules (IEC/PAS 62717), and LED luminaires (IEC/PAS 62722-2-1) will present a broad range of requirements from electrical properties to lumen maintenance and include colorimetric properties and their maintenance during the product's life. These standards include tests lasting up to 6,000 hours.

The European SSL regulatory landscape is summarized in the table. Companies that intend to sell their LED-based products in Europe should engage with a testing lab to have the products tested to the relevant harmonized safety and performance standards. Moreover, competent test labs will be able to counsel product manufacturers on the ever-shifting landscape of LED-centric regulatory issues.

COB LEDs simplify SSL manufacturing, drive broader deployment

Dense LED arrays can reduce the design complexity and manufacturing cost of solid-state lighting products and ultimately help solve the global energy crisis, writes **RON WEBER**.

The lighting market is evolving rapidly from traditional lighting sources to solid-state lighting (SSL) technology. The main drivers for this change are the need for greater energy efficiency due to rising energy costs and new legislation, both of which have global implications. With the market drive to mass adoption of SSL technology, lighting manufacturers must adapt to faster product development cycles that more closely match developments in LED technology. Developing fixtures that incorporate chip-on-board (COB) LED arrays is one avenue toward faster development, although that choice also comes with challenges in how to implement the electrical, thermal, and optical interfaces with the LED. This article provides background on COB technologies, summarizes the issues and challenges with COBs, and suggests a unique luminaire assembly and interconnect approach that simplifies luminaire design.

The world is facing a wide range of energy-related issues ranging from oft-debated global warming to diminishing fossil fuel supplies. Power generation limitations due to increasing demand or resulting from natural disasters in various regions result in brown-outs or even black-outs that directly affect quality of life for residents. These disruptions can extend to national productivity due to decreased manufacturing output at companies located in those regions. Political, economic, geographic, or logistical issues often limit adding power generation capacity to address the increased demand. Given this environment, countries around the world are fully engaged in trying to minimize their carbon footprints and decrease energy consumption, thereby lessening the strain on their energy infrastructure.

One major global effort is to decrease the energy load posed by the inefficient lighting systems in use today. Increasing global population and the resulting rise in demand for lighting can no longer be served by incandescent sources that accounted for 79% of light source sales volume in 2006. Collectively today, lighting energy consumption accounts for around 18% of the total global generated energy and cannot be allowed to continue. Simply switching to readily available, more energy-efficient light sources such as CFLs or LEDs can result in a 40% energy savings that would eliminate 630 million tonnes of CO_2 and 1800 million barrels of oil. It would further cut down on the power-generating footprint, eliminating the need for almost six hundred 2-TW/yr power plants. Although it is neither feasible nor realistic to expect this change to happen overnight, phased regulations are in place around the world to ban the incandescent bulb. These are progressing and driving the changeover to incandescent alternatives — primarily turning to the LED moving forward.

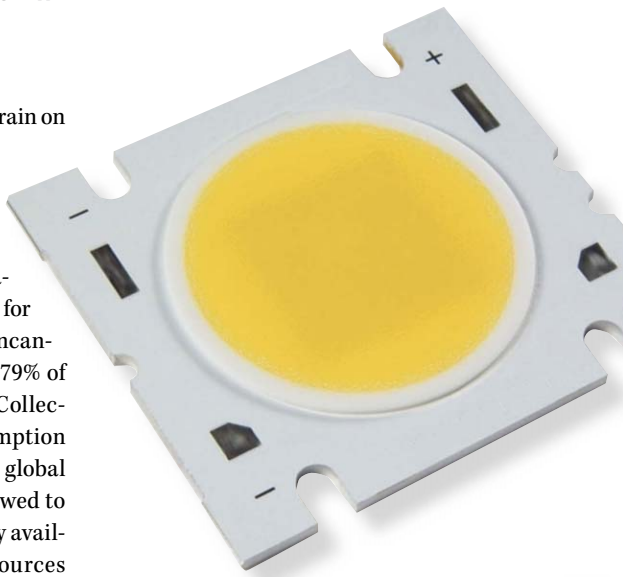

FIG. 1. A chip-on-board (COB) LED packs a dense array of LEDs.

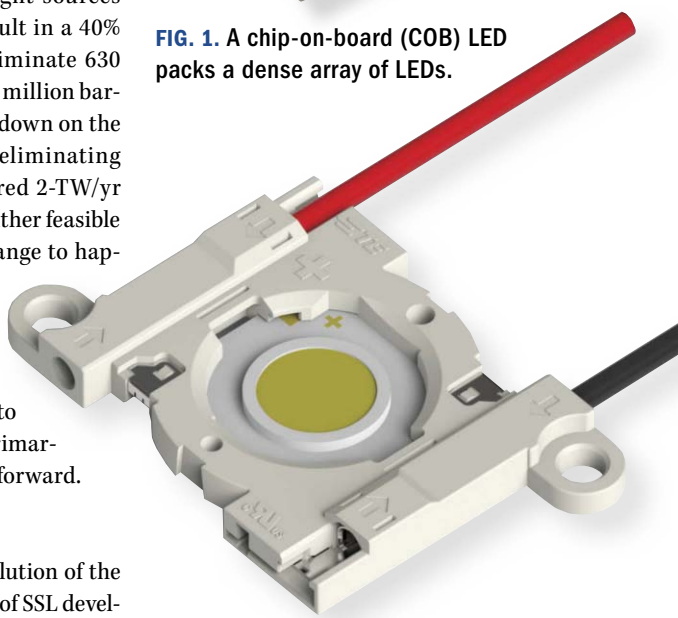

FIG. 2. Companies initially developed custom sockets for each LED from major manufacturers.

HB LED evolution

Let's move on to LEDs, the evolution of the technology, and the challenges of SSL development. LEDs have gone through a significant transition since their inception that mimics the evolution of the single semiconductor transistor device morphing into the integrated circuit we know today. Early LEDs were low-power devices used for indicating purposes and are still in wide use today across many applications. In a manner similar to transistors, an indicator LED that cost $300 in the 1960s can now be purchased for less than $0.05 in a number of different package styles. As with transistors,

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LED technology transitioned from its original format as a low-power device to a high-power device in the late 1990s/early 2000s. While these earlier devices were considered high power, they were single-die packaged emitters with very limited light output and limited practical use.

In an effort to increase light output, companies began placing multiple die in a lead-frame style package to increase light output and individually placed phosphor dots on each die to tune color. Around 2005, a new LED package was developed that eliminated the secondary LED package and placed the die directly on a metal-clad PCB substrate — collectively called chip-on-board or COB (Fig. 1). Rather than individual phosphor dots on each die, these COBs are characterized by a yellow-orange phosphor pool or slurry that covers all die and is typically centered on a white-colored substrate, giving these LEDs the nickname "fried-egg LEDs" due to their appearance.

These COB LEDs have undergone a proliferation over the past couple of years as all major LED manufacturers began offering COB products to the market. Unlike the smaller packaged LEDs that are considered point source emitters, COBs by their nature are wide area emitters with up to 204 0.25-mm^2 die packed into a 12-mm-diameter area as seen in products offered by Nichia Corporation. In some instances, larger die are used in large arrays as seen in the Bridgelux products that place 64 1-mm^2 die in a 35-mm-diameter area.

With light source areas this large, COBs are clearly positioned as broad angle emitters — their large source size becomes very difficult to effectively focus into a small beam angle. As a result, COBs are now found in applications requiring large amounts of light spread out across a large area as seen in high bay and street lighting. Still, optics such as reflectors can also enable the use of COB LEDs in applications including downlights and even reflector-based retrofit lamps.

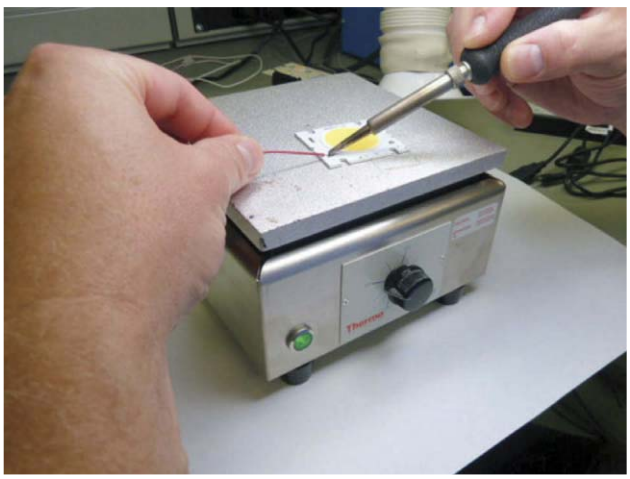

FIG. 3. Hand soldering is one option for making the electrical connection to COBs but can be unreliable and time consuming.

Connecting packaged LEDs

Over the years, multiple connector companies developed a number of sockets for the high-power LEDs that came to market. In fact, the idea has spread that an LED is just another device to be connected to. Sockets such as the TE Type LS and Type NL2 (Fig. 2) devices were dedicated to a particular manufacturer's LED package and therefore had limited applicability beyond the specific targeted LED.

The emergence of COB LEDs posed different challenges to fixture manufacturers: how to provide power to these devices and then affix them to heat sinks in the lighting fixtures. The traditional method was to hand-solder the wires to the pads on the substrate (Fig. 3) and then secure these assemblies with screws to the heat sink — a process that was time consuming and subject to variability. As with the earlier discrete devices, this presented an ideal opportunity for socket solutions.

TE and other connector companies addressed this emergence of initial COB devices the same way earlier discrete LED packages were addressed: custom sockets. As other COBs started to enter the market, connector manufacturers realized that the status quo method of developing a socket for each would be prohibitively expensive and time consuming, resulting in never-ending efforts forever chasing the next new COB to enter the market.

With well over 50 different COB products commercially available around the world from multiple manufacturers, finding a single solution to address each would be a challenge to say the least. Aside from the fact that all were rectangular, all had two electrical contact pads, and most had circular light emitting surfaces, there were few other dimensional similarities. The challenge for connector companies was how to address these varied but similar COB LEDs with a minimum of engineering and tooling expenditure while providing a future-proof and flexible platform based product.

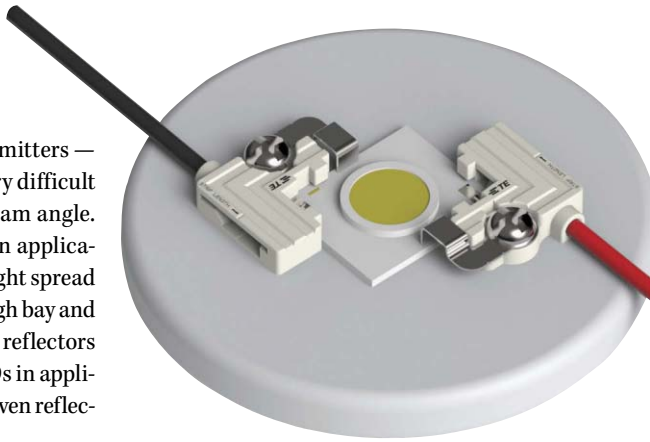

FIG. 4. A pair of holders that reference the corners of the LED can work with many different COB LEDs.

Scalable interconnects

One solution to the interconnect challenge is a flexible, scalable, platform-based socket. An analysis of available COBs yielded a crack in the shell of these "fried egg" LEDs. While not exactly identical, there are similarities between contact pad locations that, when combined with the rectangular nature of the devices and diagonal contact pad placement, form the basis for the platform solution. As a result, a holder product, referenced off the corners of the COB, could yield a virtually limitless array of use scenarios with the varied COBs available on the market as well as those to come in the future.

The substrate differences among COB LEDs from difference manufacturers, however, added yet another issue that needs to be tackled by socket/holder suppliers. While most of the early COBs incorporated aluminum substrates, further investigation of the commercially available COBs indicated a number of COBs that are based on ceramic substrates (typically aluminum nitride). While not a significant differentiator, these two substrate variants have physical features that differ enough to require special handling due to their different material properties.

The aluminum substrate COBs are rather robust and in some instances are mounted using machine screws. On the other hand, ceramic-based COBs create some frustration for fixture manufacturers since unlike aluminum-based substrates where they could simply secure the COBs with a screw to a heat sink, these ceramic substrates are far too brittle to secure with screws and thereby mandate some sort of secondary attachment to ensure suitable thermal performance. This attachment needs to be accomplished using thermal adhesives or by a mechanical holder that provides normal force to the heat sink or thermal pad, mechanical attachment, and electrical interconnection.

Holder devices that accommodate the COB nuances mentioned in the previous paragraphs are appearing on the market. An example of one such platform solution is the TE Scalable LED Socket connector that utilizes the corners of the COB as a reference. In this manner, the two datums formed by the sides of the COB can be used to positively locate the electrical contact on each of the COB's electrical pads.

Moreover, the diagonally opposed contact pads on most COBs can allow the luminaire industry to leverage the symmetry. The symmetry can enable use of the same socket assembly on both corners of the COB (Fig. 4). By doing this, SKU (stock keeping units) or model numbers are drastically reduced by eliminating the need for right and left versions of the socket, providing an advantage for socket makers, distributors, and SSL manufacturers.

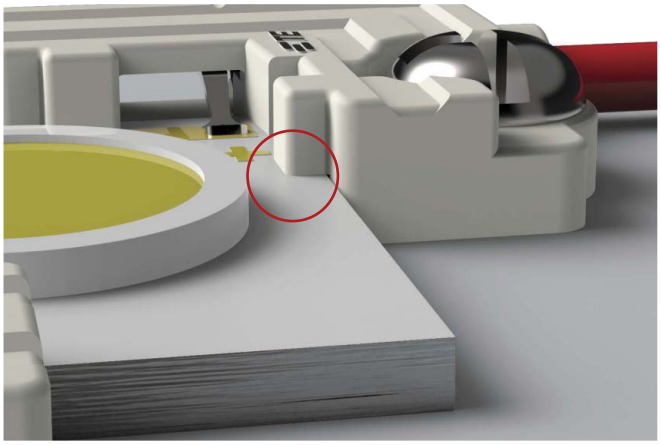

FIG. 5. The COB holders can directly place force on thicker aluminum substrates.

Managing substrate height

The variability of COB thickness poses yet another design challenge for a socket product. COB substrates are available in a variety of materials and thicknesses that need to be accommodated. The thinner and more brittle ceramic packages can easily crack under pressure when used with flexible thermal interface pads and therefore consequentially use greases as thermal interface materials

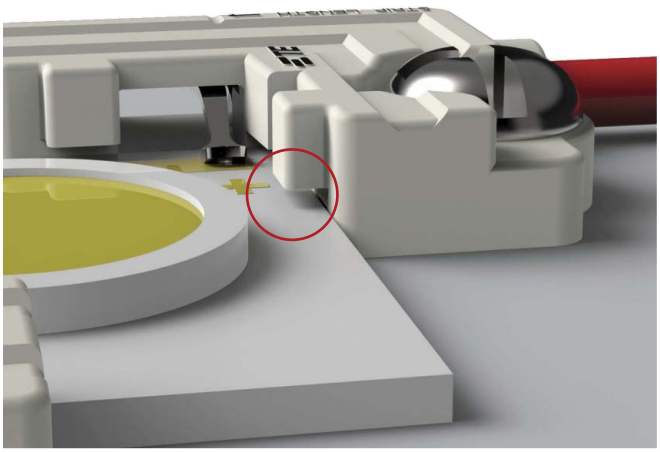

FIG. 6. The holders must leave a gap on the thinner and brittle ceramic substrates.

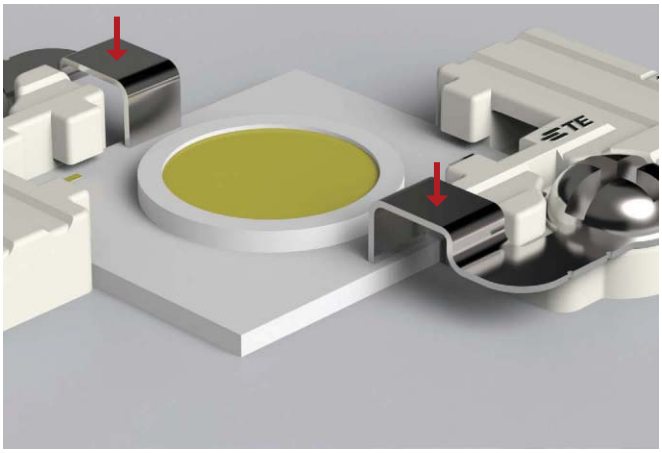

FIG. 7. Springs can secure ceramic substrates against the TIM and heat sink.

(TIMs) to optimize the thermal path from the LED substrate to the heat sink. On the other hand, the more durable aluminum substrates can use grease or flexible TIMs.

Any holder being considered by an SSL manufacturer needs to be evaluated relative to how it accommodates these varying stack heights posed by COB applications. One method is commercially available that utilizes a combination of optional thermal springs and housing ledges to accommodate both types of COBs. An example using an aluminum substrate COB is shown in Fig. 5. The red circle indicates how the housing is used to secure the COB against the heat sink.

When the same system is used with the thinner ceramic substrates as shown in Fig. 6, clearance needs to be provided to avoid exerting pressure on the ceramic substrate. The housing design naturally clears the thinner ceramic COB as indicated by the red

circle. Since the electrical contact spring is inadequate to provide an appreciable normal force for thermal contact, a secondary thermal spring is incorporated and is seen in Fig. 7. A pair of these springs can exert just the right amount of force on a ceramic device to ensure optimal heat transfer when used with most commercially available thermal greases.

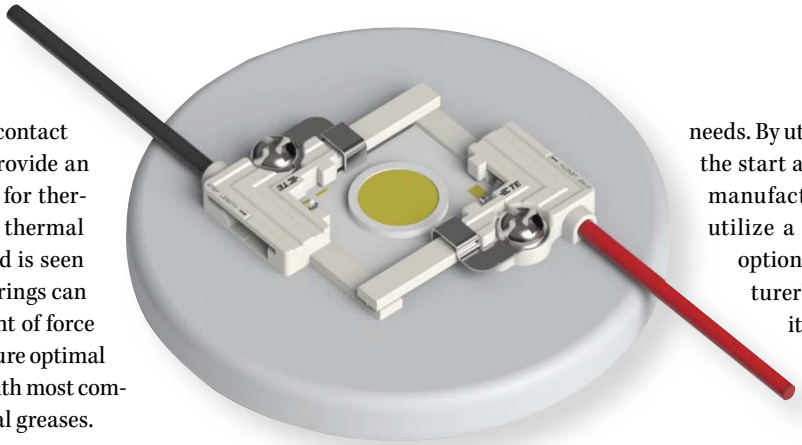

FIG. 8. By adding arms to the corner holders, companies can supply a one-piece COB interconnect to SSL manufacturers.

Simplifying manufacturing

While a two-piece socket design affords a significant level of scalability to accommodate a wide range of COBs, some fixture manufacturers prefer to only handle a single part. Additional levels of scalability can be incorporated into a two-piece design by the relatively simple addition of two arms oriented at 90° to each other. These arms essentially create a scalable, factory-assembled one-piece housing. A customized holder is then available to fit a specific manufacturer's COB LED (Fig. 8).

A scalable approach to the interconnect enables a more generic two-piece design or a customized one-piece design, and either can be used by the fixture manufacturer with very little cost difference between the two. Consider the option a stepping-stone approach. A lighting manufacturer can minimize the interconnect investment during prototyping by launching the fixture using a readily available two-piece holder solution. Once production ramp starts, the manufacturers can switch to a more manufacturing-friendly one-piece design.

Ideally, having a single holder to accommodate all COBs would be the perfect solution. Given the slight differences in pad locations between commercially available COB products and the different plating styles commonly used, that perfect solution is still elusive. Nonetheless, with a scalable holder solution, solderless interconnections to a broad range of COBs are possible with a very small number of socket SKUs that can accommodate a wide range of commercially available products.

COB corner holders are also quite adaptable. An additional benefit to the holders referencing off the corners of a COB is that the applicability of these holders can extend beyond COBs. By using the same corner holders used to provide power into a COB, large printed circuit boards containing massive arrays of LEDs can be powered in a similar fashion through pads located on the corners of the circuit board.

In conclusion, COB holders, in particular those that reference off the device corners, offer lighting fixture manufacturers a unique and flexible termination solution for their COB LED attachment and interconnect needs. By utilizing a holder designed from the start as a scalable platform, fixture manufacturers gain the flexibility to utilize a broad range of light source options. From a COB LED manufacturer's point of view, the availability of a common holder design provides a stable reference for manufacturers designing a new COB package since the use of pre-defined contact pad locations ensures the availability of an off-the-shelf holder solution when a new COB is released to the market.

The global march toward energy efficiency continues. LED lighting will play a major role and, as with all new technologies, efficiencies are increasing while costs are dropping. The need for cost-effective LED lighting is putting a renewed emphasis on cost and manufacturability, which is where both COB LEDs and the COB holders offer customers an ideal cost-effective solution that will accelerate LED adoption.

automotive | LEDS STANDARDS

LEDs light the road ahead in automotive applications

MORAND FACHOT explains that international standards and evolving LED technology are set to play a key role in the widespread transition to solid-state lighting in automotive applications.

The majority of drivers feel stressed in poor visibility conditions, particularly at night when the ability to perceive and judge distance is severely impaired. Despite much lighter traffic on the roads at night, around 40% or more of all traffic fatalities occur in many countries, such as the US, during night-time hours. The strain eases and safety greatly increases if the road ahead is well lit. The recent introduction of LED-based lighting for autos is set to improve driver safety and comfort at night, as well as during the day, and offer additional advantages in cabin lighting. Moreover, international standards will play a key role in the move to solid-state lighting (SSL) in the auto.

The need for drivers to see other vehicles — and to be seen by them — after dark emerged naturally as soon as cars first appeared on roads. Lighting had been present on horse-drawn vehicles for a long time because of the same requirement. Initially, in the 1880s, cars were fitted with acetylene and oil lamps. Vehicular lighting had begun a long evolutionary journey.

Early car electrical systems were rather unstable and the lamps were subjected to harsh conditions, such as shock and widely varying climatic conditions and temperatures. All of these contributed to the somewhat slow large-scale implementation of electric lamps, which started only in the 1920s. Other lamps besides headlamps and tail lights have been introduced gradually to meet additional needs. They include fog lamps and various kinds of signalling lamps such as indicators and brake, emergency, parking, and reverse lights.

MORAND FACHOT *is the communications officer for the International Electrotechnical Commission (IEC).*

FIG. 1. The use of LEDs in daytime running lights, such as in this Hella design for the Audi A8, and combination rear lamps reduces energy requirements during the day by 95%.

Slow initial progress

Because the ability to see ahead properly is fundamental to safe night driving, improving the performance of headlamp lightbulbs has always been seen as essential. Until the introduction of high-intensity discharge (HID) lamps, also known as xenon lamps, the light source used in incandescent headlamps was a tungsten filament placed in a vacuum or inert-gas atmosphere inside a bulb or a sealed unit. The main drawback of tungsten bulbs is that their luminous flux (intensity) drops significantly after some 1,000 hours. The tungsten bulbs were further improved with the introduction of halogen gas in the bulbs in the early 1960s. Halogen bulbs had a higher luminous flux and longer useful lifetime.

Xenon lamps that generate light based on the principle of gas discharge were first fitted to motor vehicles in the early 1990s. The xenon lamps represented a major improvement over halogen lamps as their color temperature is closer to daylight, they are brighter, they have a greater range, they better illuminate the edges of the road, and they last at least twice as long as prior lamps. The main drawback to xenon is glare, which can be reduced by various automatic devices. In spite of their qualities, they are not as widely adopted as halogen lamps.

The introduction of LED-based automotive lighting is a relatively recent development. The first LED rear lights and headlamps

were fitted to production vehicles in 2003 and 2006, respectively. The benefits of LEDs, especially for headlamps, are already obvious, including the fact that their light color is very similar to daylight. LED headlamps are now being introduced by all major car manufacturers and are seen as the future of automotive lighting.

Besides headlamps, LED-based lights can be used for general and interior lighting. Their higher energy efficiency translates into lower fuel consumption and noxious emissions, helping manufacturers meet ever more stringent regional or national limits. LED light sources have a much longer lifetime that can outlast that of the vehicle. They also offer an unprecedented level of design versatility that is essential for manufacturers, allowing them to differentiate their vehicles from the competition.

International regulations and standards

Road vehicles are produced and traded globally and are used regularly across national borders. The need for international standards is clear as road safety requires that lights are standardized in terms of characteristics such as performance, color durability, and interchangeability.

The UNECE (UN Economic Commission for Europe; www.unece.org) is the international body that sets many of the regulations for road vehicles through its World Forum for Harmonization of Vehicle Regulations (WP 29).

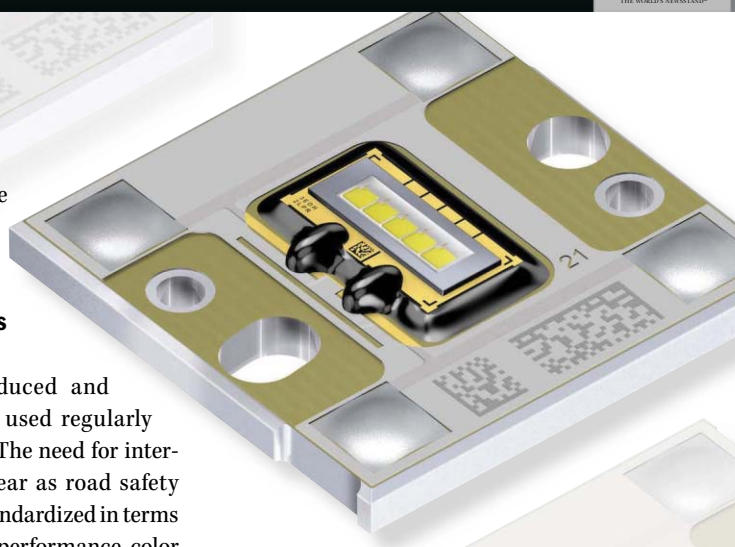

FIG. 3. An Osram Ostar LED module for auto headlamps integrates multiple LEDs.

The UNECE Working Party on Lighting and Light-Signalling (GRE) is the subsidiary body that prepares regulatory proposals on active safety for vehicle lighting and light signalling. This group conducts research and analysis to develop lighting requirements for vehicles. Most countries — with the notable exception of the US and Canada, which have their own directives — recognize the UNECE Regulations and apply them in their own national requirements. Much of the GRE's work depends on and references various International Standards on lighting for road vehicles prepared by the International Electrotechnical Commission (IEC; www.iec.ch).

The relatively recent introduction of LED-based light sources has led to changes in standards regulating lighting requirements. Initially fitted to the high-end/luxury segment of the car market, LED lights are rapidly spreading to all categories of vehicles due to their countless benefits and flexibility. As these lights represent a completely new concept, they require new standards to ensure they meet road safety regulations and operate properly in a very demanding environment.

IEC Subcommittee 34A: Lamps prepares international standards for all types of lamps (filament, discharge, or LED), for general lighting and for road vehicles. These standards identify their dimensional, electrical, and luminous requirements as well as their performance requirements.

Lamps for road vehicles are submitted to a particularly harsh environment and since they have a direct impact on road safety, tests are essential to ensure they meet all the necessary requirements.

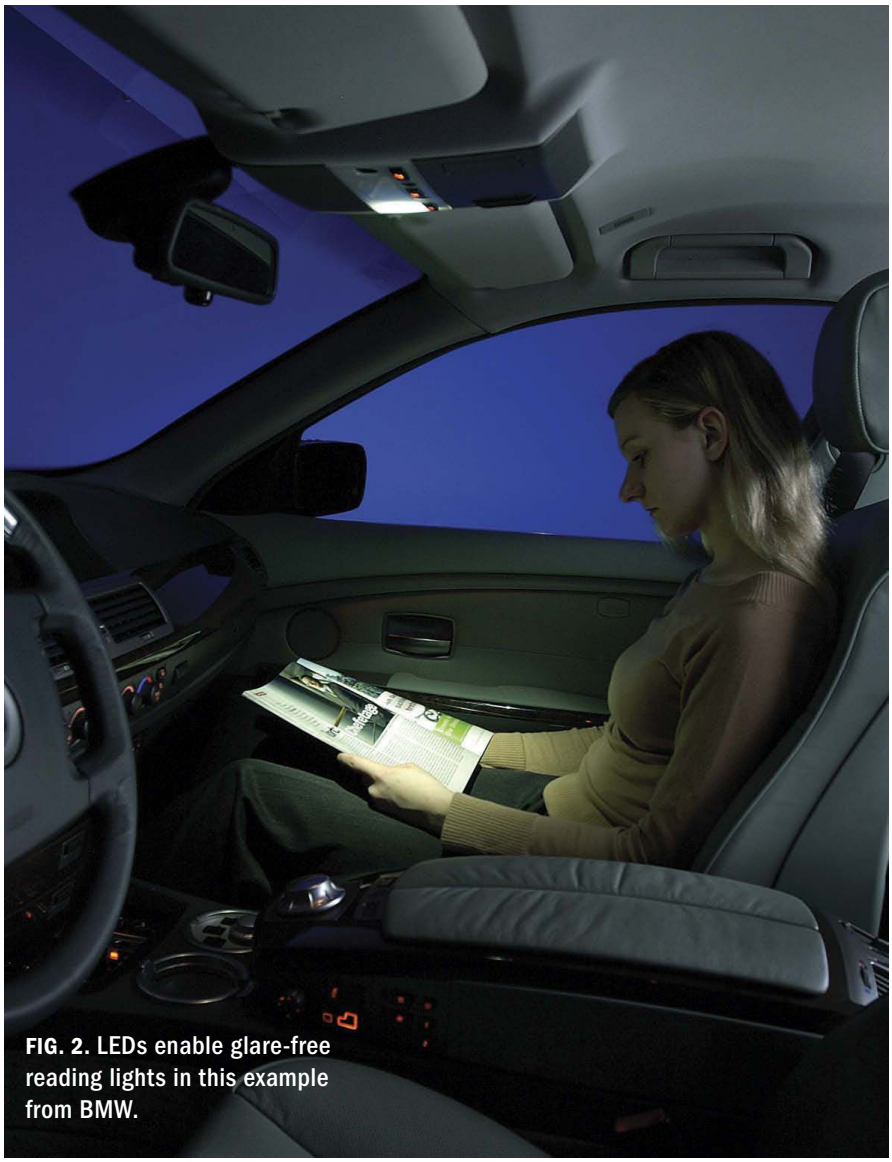

FIG. 2. LEDs enable glare-free reading lights in this example from BMW.

FIG. 4. LEDs form distinctive low-beam headlamps in the Audi A8.

Differing requirements

The basic function and interchangeability of filament and discharge lamps for road vehicles differ from those of LED light sources. The former types must comply with the IEC 60809 International Standard that defines the dimensional, electrical, and luminous requirements of lamps for road vehicles. In particular, this standard defines the markings, bulbs, dimensions, colors, caps, and bases.

LED light sources, which are based on modules (LED components used by the industry), are not covered by IEC 60809 but by other IEC standards specific to LED modules. However, another International Standard, IEC 60810, which sets out the performance requirements of lamps for road vehicles, applies to the three types of lamps.

LED light sources must meet conditions that do not necessarily apply to filament and discharge lamps, in regard to UV radiation, color maintenance, and electromagnetic compatibility. As LED light sources have a longer rated lifetime than filament or discharge lamps, their lumen maintenance is assessed differently.

Another issue that manufacturers have had to deal with is thermal management, and LED modules and light sources often come with integrated heat sinks. Unlike their filament and discharge counterparts, LED light sources are mainly of the non-replaceable type and are usually intended as components for integration into the luminaire or lighting device by manufacturers. They are designed and meant to be indivisible parts of a lighting or light signaling device, or to be elements of a module or light engine. The auto industry has developed replaceable LED modular sources, usually intended for sale to the general public as a replacement part.

Unparalleled flexibility and benefits

LED light sources can replace all other types of automotive lamps. They are available for headlamps (high and low beam), brake lights, rear combination lamps, center high-mount stop lamps, daytime running lamps (DRLs), turn signals, interior reading lights (map lights), dome lights, accent lights, fog lamps, and position and marker lamps. Moreover, LEDs are being used for ambient lighting and in dashboard and instrument lighting.

In addition to enhanced driving safety and comfort, LED light sources offer many other benefits:

- Lighting flexibility: Lighting requirements and limitations vary greatly according to traffic conditions. LED lighting solutions allow the optimal use of environmental and traffic-related dynamically controllable light distribution patterns such as dynamic bending of light or adaptive front lighting systems (AFSs), already used for other types of automotive lamps. Such adaptive lighting is particularly important to avoid blinding other drivers when crossing or following other vehicles, especially in curves, or to better see fixed or moving obstacles on road sides. LED lighting sources are also dimmable.
- Durability and efficiency: LEDs for automotive lighting have a much longer rated lifetime and use less energy than filament or discharge lamps. LEDs are up to 40% more energy efficient than the former sources. Since less energy for lighting translates into lower fuel consumption, this is a significant feature at a time when tighter consumption and emission rules are introduced in all countries even though road vehicles are required now to use DRLs.
- Design flexibility: A very important benefit of LED lighting solutions for car manufacturers is the design flexibility they offer. Car design bureaus have much greater freedom to come up with innovative designs using lighting to accentuate or attenuate certain shapes and give cars a common brand signature. LEDs were first fitted to vehicles from the exclusive segment of the market, but they are found now in all classes of cars.

Potential not exhausted

LEDs for automotive or other applications are constantly evolving. Their potential in the automotive sector is set to expand as LED modules improve and with the introduction of new technologies such as OLEDs (organic LEDs), which produce a comfortable and homogenous light.

Night driving does not depend only on good vehicle lighting but also on superior road signage and lighting. LEDs are also increasingly showing the way in this very significant area. More benefits of LED lighting have yet to been discovered and it can be safely assumed that they will have a bright future in the road traffic environment.

Improve LED manufacturing via in-line monitoring and SPC

In-line monitoring of defects on LED wafers allows manufacturers to understand which defects impact yield and to apply that information in a constant effort to improve yield, explains **STEVEN CHEN**.

LED manufacturing is undergoing a tremendous transformation. The evolution to high-brightness LEDs, larger wafer size, and new complex architectures make LED manufacturing more challenging than ever before. Even though these trends greatly benefit the advancement of the solid-state lighting (SSL) industry in terms of LED efficiency and performance, they can potentially impact yield in a negative way. In order for LED manufacturers to stay competitive in this dynamic environment, they need to have a comprehensive in-line process control strategy to improve the yield and drive down the cost of LEDs and SSL end products.

Currently, most LED manufacturers rely on inspection tools to analyze wafers and document defects of interest (DOI). Defect density is typically utilized as the gauge for statistical process control (SPC). However, the drawback of this approach is the fact that there can potentially be a lot of nuisance defects that do not cause yield loss. In looking at a defective wafer through an inspection tool, how do you determine which defects are killer defects that impact the yield or electrical performance, and which defects are simply a nuisance? Manufacturers need to detect killer defects at the earliest possible time in terms of the repetitive epitaxial-growth wafer-production runs in an MOCVD (metal organic chemical vapor deposition) reactor. Ideally, the manufacturer will optimize the MOCVD process over time to reduce killer defects, whereas a line without such monitoring can lead to what's often called an excursion — or the shutdown and revamping of part of the manufacturing process.

STEVEN CHEN *is a process control solutions technologist at KLA-Tencor Corporation.*

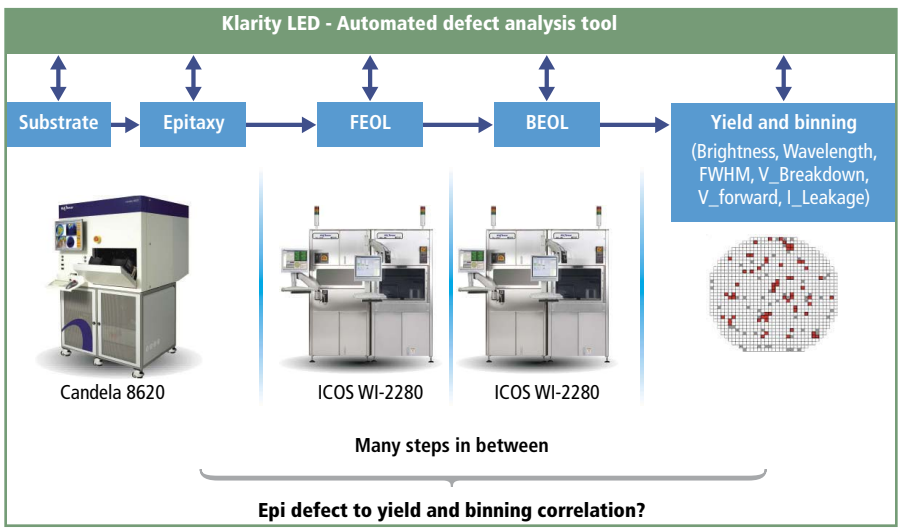

FIG. 1. In-line monitoring should be applied across the multiple stages of the LED manufacturing process.

We know that in-line monitoring is critical in determining how defects affect the yield and a proper strategy would have tremendous return on investment (ROI). Further to the point, the current method of using total defect density is impractical. Hence, we will introduce a systematic methodology to identify yield-impacting defects and mapping the relationship of defects to yield.

LED manufacturing process

Before we jump into the details of the advanced process control technique, we want to take a step back and go over the LED manufacturing process flow. Understanding this process flow can help us to understand where crucial inspection points occur, and how process control can help improve time to corrective actions, which translates to higher ROI. A simplified version of the LED manufacturing process flow is depicted in Fig. 1. In general, the manufacturing process consists of four essential stages — namely substrate, epitaxy, FEOL (front end of line), and BEOL (back end of line) — before going to final assembly.

First of all, the main substrate utilized in the production of LEDs is sapphire, gallium arsenide, or silicon carbide. There are also other initiatives for alternative substrates such as gallium nitride and silicon. With any substrate, a crystalline boule is produced in a similar fashion as the semiconductor process in the integrated circuit (IC) industry. The boule is normally sliced into very thin wafers with a diamond saw, and after slicing, they are polished via a rigorous process before being shipped to the LED manufacturer for further processing.

In the next stage known as epitaxy, additional layers of semiconductor crystal are grown on the surface of the wafer. MOCVD is a popular method for the epitaxial growth of

p and *n* layers with quantum wells in between. The typical thickness of the *p* and *n* layers combined is around a few microns. It is important to have an inspection point before MOCVD because poor quality of the incoming substrate can potentially be the culprit of future electrical probe test failures downstream — such as failing forward voltage and reverse leakage current specifications.

Furthermore, defects from substrate and epitaxial processes can impact device performance, reliability, and yield. Equipment such as the Candela 8620 is capable of performing unpatterned wafer inspection at the substrate and epitaxy stages. It is crucial to catch defects at these early stages to allow faster time-to-root-cause determination and improved MOCVD reactor uptime and yield. In addition, the wafer inspection system is not only able to catch defects precisely, but it also classifies the defects accurately. This information is important for in-line process monitoring and SPC control.

Wafer ID	Yield (%)
Wafer 1	60
Wafer 2	70
Wafer 3	80
Wafer 4	90
Wafer 5	60
Wafer 6	70
Wafer 7	80
Wafer 8	90
Wafer 9	75
Wafer 10	80
Wafer 11	90
Wafer 12	80
Wafer 13	60
Wafer 14	70
Wafer 15	90
Wafer 16	80
Wafer 17	80
Wafer 18	70
Wafer 19	80
Wafer 20	70
Average	**76.25**

TABLE 1. Yield data for a theoretical set of wafers.

Front-end processes

The next steps after epitaxial growth are the FEOL steps. FEOL in the LED process is similar to the semiconductor process but with fewer steps, and involves the wafers going through cleaning, lithography, etch, metallization, deposition, and anneal before going to BEOL. Patterning for enhancing light extraction also happens in the FEOL steps.

It is important to realize that, for any single set of wafers that goes through a production run, bad die bear the same cost as good die because bad die also have to be processed all the way through the LED manufacturing steps. Therefore, early defect detection and remediation when a line is started is the key to reducing manufacturing cost over time.

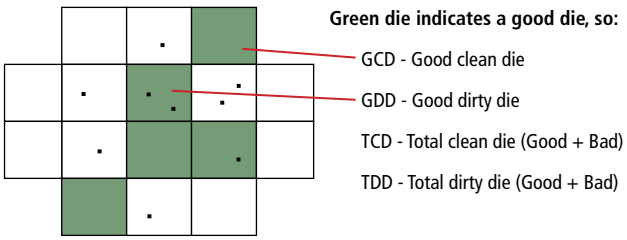

FIG. 2. Monitoring tools can identify defects and then correlate them to yield.

As LED structures become more complex, the ability to bin defects and understand the location of defects becomes increasingly important and requires inspection through the FEOL stages. The same defect on different LED structures will have different yield or electrical performance impact. In addition, defects with certain attributes are more critical and yield relevant than others at certain locations.

The inspection equipment's defect detection sensitivity and accurate classification capabilities are needed to ensure that manufacturers have a good set of data for analysis and process control. Wafer inspectors such as the WI-2280 are capable of inspecting all patterned wafers at various process steps such as lithography, etch, and metallization. In addition, the WI-2280 has a high defect capture rate, a unique defect classification capability, and an advanced recipe tuning engine that can be tightly integrated with advanced analysis software for process control and further evaluation.

Back-end processes

After the wafers go through FEOL, they go on to BEOL where die singulation, testing, and sorting take place before final assembly. Pre-dicing and post-dicing singulation inspection is essential to enable process control and improve the yield. Post-singulation should look for defects to ensure that the singulation tooling does not damage the wafers. For example, scratches on the die and the presence of foreign matter can potentially cause the die to crack during testing. The WI-2280 is also utilized for BEOL inspection to look for yield-relevant defects.

After die singulation, die attachment and wire bonding take place before encapsulation and final assembly. Packaged LED inspections to examine assembly defects such as missing die, defective wire bonding, and misplacements also happen at this stage before taping and shipping them out.

Finally, it is crucial to tie these inspections together and perform process control. The inspection equipment's defect detection sensitivity and classification capabilities

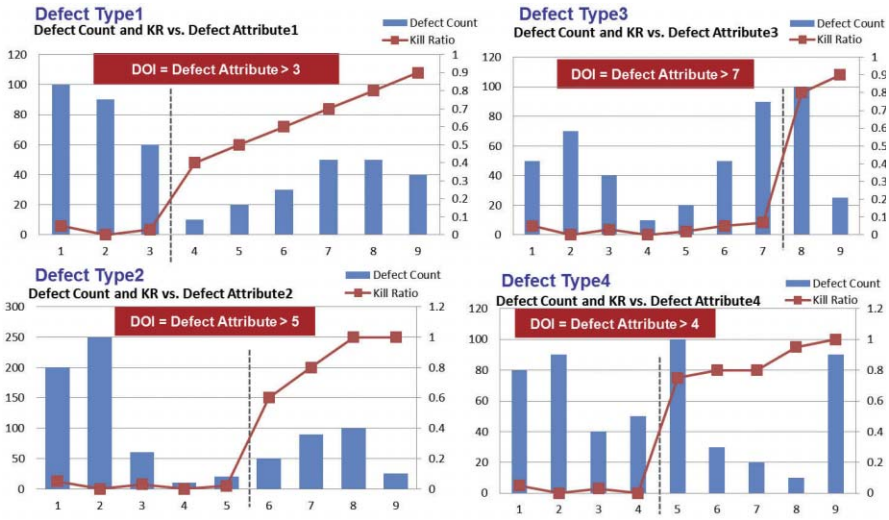

FIG. 3. A kill ratio study can be performed on multiple types of defects.

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need to be matched with yield management software that ties all the data together. The software needs to be capable of taking the inspected data from various inspection points and providing analysis and monitoring. In the next section, an example of in-line monitoring is introduced to demonstrate how to tie the data together to provide meaningful analysis and results.

Methodology overview

As mentioned before, it is crucial to distinguish yield-impacting defects from nuisance because not all defects impact the final yield. Thus, we need to understand the relationship between epitaxial defects and their impact on yield, as well as to create a systematic approach in separating yield-impacting DOI from nuisance. In order to establish a proper process control loop, advanced defect equipment such as that depicted in Fig. 1 is needed. Defect information inspected from substrate, epitaxy, FEOL, and BEOL can feed into an automated defect analysis tool. In the case presented here, we are going to focus on whether the epitaxial defect density correlates to yield.

One approach to separate yield-impacting DOI from nuisance is to use what is called kill ratio analysis. Kill ratio represents a proportion of defects estimated to cause die failure. The kill ratio is derived from data gathered over prior production runs and is used to find the amount of defects on a current inspection that will cause die failure at the end of the process.

In order to understand how kill ratios help in separating yield-impacting DOI from nuisance, we need to understand the kill ratio model terminology. Fig. 2 illustrates this concept. Bin data represents good or bad die identified by bin code. In addition, the defect data identifies clean or dirty die. A clean die contains no detected adder defects (such as particles), while a dirty die contains detected adder defects. The square boxes represent die and the dots represent defects. Green boxes indicate good die while white boxes indicate bad die. Therefore, good clean die means good die without defects. Good dirty die means good die that have defects. Furthermore, we also have total clean die and total dirty die.

DOI	Low-impacting DOI bin	Yield-impacting DOI bin
Defect_Type1	Defect attribute ≤3	Defect attribute >3
Defect_Type2	Defect attribute ≤5	Defect attribute >5
Defect_Type3	Defect attribute ≤7	Defect attribute >7
Defect_Type4	Defect attribute ≤4	Defect attribute >4

TABLE 2. Yield-impacting defect of interest definition.

The equations below are the yield and kill ratio formulas.

Yield formula:

$$Y_{Dirty\ Die} = Y_{Clean\ Die} * Y_{Particles}$$

$$\frac{(GDD)}{(TDD)} = \frac{(GCD)}{(TCD)} * (1 - KR)$$

Kill ratio formula:

$$KR = 1 - \frac{(GDD * TCD)}{(GCD * TDD)}$$

Potential die loss: dirty die * kill ratio

Generally, yield is simply the number of good die divided by the total number of die. In this case, however, we are focused on the yield impact strictly of the die that have at least one instance of the defect of interest, and that leads to the aforementioned formulas. In an actual production scenario, manufacturers would perform such an analysis on different types of defects. By binning defect attributes such as defect size and defect location with the kill ratio results, one will finally be able to observe the correlation to yield. In other words, defects with higher kill ratio have more negative impact on the yield.

After the data is gathered, we need to obtain accurate bin sort data, a list of wafers, yield information, and defect types from the inspection tools. Then, we use a yield management software tool, such as KLA-Tencor's Klarity LED, to perform the analysis. Here, we need to ensure that the defect map accurately aligns with the bin sort map. It is crucial to have an accurate wafer alignment because it is the basis of the kill ratio analysis. Using this kill ratio information, we can derive the yield-impacting DOI definition. Once we have

Wafer ID	Low-impact defects	Yield-impacting defects	Total defects	Yield (%)
Wafer1	60	1300	1360	60
Wafer2	710	1000	1710	70
Wafer3	1050	480	1530	80
Wafer4	930	60	990	90
Wafer5	60	1140	1200	60
Wafer6	120	950	1070	70
Wafer7	550	450	1000	80
Wafer8	1100	30	1130	90
Wafer9	750	560	1310	75
Wafer10	730	405	1135	80
Wafer11	1110	25	1135	90
Wafer12	620	360	980	80
Wafer13	70	1080	1150	60
Wafer14	140	890	1030	70
Wafer15	1650	75	1725	90
Wafer16	1000	275	1275	80
Wafer17	1100	230	1330	80
Wafer18	170	760	930	70
Wafer19	400	140	540	80
Wafer20	700	580	1280	70

Total defects

UCL	Number of sample failed	Yield (%)
1600	2	76.25 + 3.75
1400	3	76.25 + 3.75
1200	8	76.25 – 0.62
1000	15	76.25 – 1.25
800	19	76.25 – 0.20
600	19	76.25 – 0.20
400	20	76.25 – 0.00
200	20	76.25 – 0.00
Example: UCL = 1400		

Yield-impacting defects

UCL	Number of sample failed	Yield (%)
1000	3	76.25 – 16.25
900	5	76.25 – 12.25
800	6	76.25 – 11.25
700	7	76.25 – 10.54
600	8	76.25 – 10.00
500	9	76.25 – 9.03
400	12	76.25 – 5.83
300	13	76.25 – 5.10
200	15	76.25 – 3.92
100	16	76.25 – 3.44
Example: UCL = 1000		

FIG. 4. Tables define yield-impacting defects compared to total defects and the examples of setting control limits.

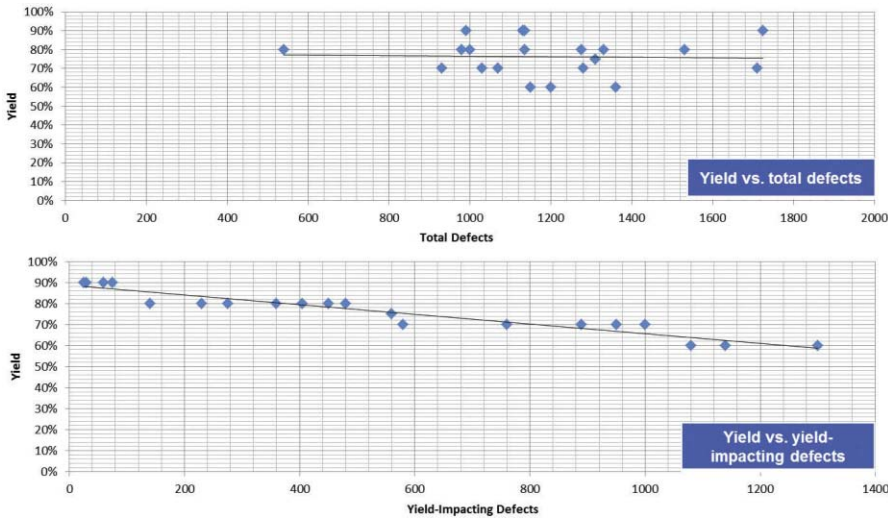

FIG. 5. Correlation charts show that yield decreases relative to yield-impacting defects.

obtained the DOI definition, we can apply it to all wafers. Upon finishing the kill ratio analysis, we can then identify yield-impacting defects by correlating the defect counts to the final bin yield. Finally, we can also obtain trend charts and be able to set upper control limits and SPC controls. The analysis is repeated until the yield-impacting DOI definition is satisfied.

Example and experimental results

Table 1 includes an example of a theoretical yield study and correlation results that illustrate this advanced defect identification methodology. In the example, assume that we are given 20 wafers with individual yield information and an average or baseline yield of 76%. Layer, class, size, wafer zone, in-die region, and signature membership are a few examples of defect attributes that can be analyzed. In this case, we take defect size as the attribute under study while Klarity LED was used to correlate yield-impacting defects with defect size.

In Fig. 3, we illustrate how to determine the yield-impacting defect attributes for four different theoretical defect types. Starting with a certain defect type, the defect count and the kill ratio with respect to its defect size are plotted. A dotted threshold line is drawn whenever sudden kill ratio jumps appear. In the case of defect type 1, defect size greater than three is the threshold where the kill ratio makes a significant jump. The same experiment goes for defect type 2, defect type 3, and defect type 4. Essentially, the defect size binning is based on the kill ratio threshold number. Potentially, one can have as many segments as one likes in order to see the impact of the yield with any defect size combination.

After performing kill ratio analysis on all defect types, the final yield-impacting DOI definition is shown in Table 2. Bin 1 indicates a low-impacting DOI bin and bin 2 shows yield-impacting DOI bins that contain killer defects.

The next phase of the analysis is to apply the yield-impacting DOI definitions to each wafer analyzed. Ultimately, we need to sum up all yield-impacting defects and see how well they correlate with the final yield. Twenty wafers with their total number of yield-impacting defects and total defects are shown in Fig. 4.

You can see that the total defect counts do not correlate to yield well. For example, if one sets the upper control limit (UCL) at 1400 total defects, three wafers have defect counts greater than 1400. These are the wafers that contain the most defects; however, their yields are relatively high compared to the baseline average yield of 76.25%. Clearly, many of those defects do not translate to yield loss.

On the other hand, if one sets the UCL to 1000 yield-impacting defects, again, three wafers have more defect counts than 1000. Interestingly, their yields are 16.25% lower than the baseline yield. As a result, one does not find wafers that have high yield-impacting defect counts with high yields. This further solidifies the methodology.

Fig. 5 depicts two correlation charts using these twenty wafers. The top graph compares yield versus total defect counts, and the bottom graph plots yield versus yield-impacting defect counts. The bottom graph makes more sense because it shows that as the yield-impacting defect counts increase, the yield decreases. SPC control on yield-impacting defects can be established based on the findings.

Moving to Fig. 6, we see that wafers with high total defect counts do not translate to

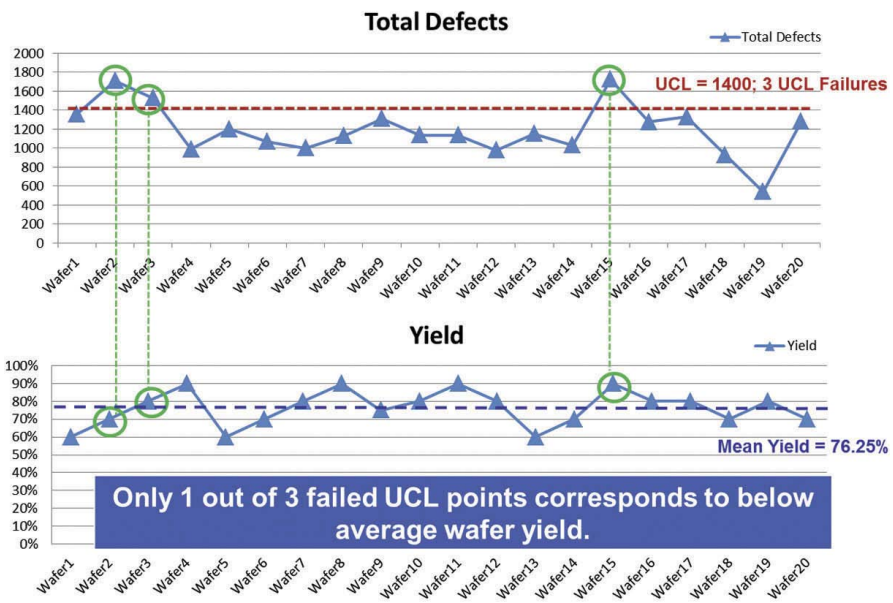

FIG. 6. SPC monitoring set based on total defects doesn't correlate with a yield impact.

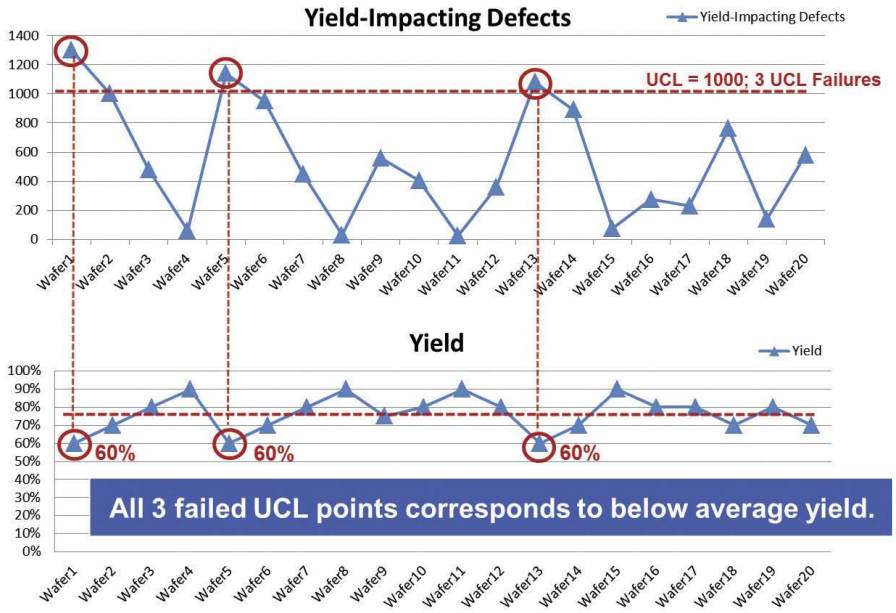

FIG. 7. SPC monitoring set based on yield-impacting defects correlates with the wafers with the lowest yield.

low wafer yield. With a UCL of 1400 defects, only one out of three wafers corresponds to below average yield. There is no correlation between total defects to yield. Therefore, one will be headed in the wrong direction if SPC is set based on total defect counts.

On the other hand, Fig. 7 shows that high yield-impacting defects translate to low wafer yield. In this example, with a UCL of 1000 defects, all wafers that failed this control limit have below average yield. Therefore, SPC control can be established.

As one can see, in-line monitoring is critical to the LED manufacturing process, and a method of separating yield-impacting defects from nuisance defects is needed. Given that the kill ratio correlates with defect attributes such as defect size, kill ratio analysis provides important guidance in setting defect attribute binning to identify yield-impacting defects. Moreover, the defect-to-yield correlation methodology provided in this article can help LED manufacturers learn more about yield-relevant defects systematically. LED manufacturers can then implement SPC to avoid expensive excursions and to realize optimum ROI.

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Dimming multiple LED strings enables color-tunable luminaires

DAVID ZHANG explains that you can use analog dimming, PWM dimming, or a mix of the two to achieve color-mixing SSL products with the application dictating the best choice.

In many solid-state lighting (SSL) applications, such as architectural, area, and downlighting, color accuracy is very important. Moreover, an increasing number of products support dynamic color tuning — to set the white point or CCT and/or to enable dynamic full-color products. LEDs are ideal light sources for achieving a precise color. The color of LED lighting can be changed by mixing different colors of LEDs, such as red, blue, green, yellow, and white. When mixing LED colors, one or more strings of LEDs needs to be dimmed to realize the desired color mix. There are different methods for achieving LED dimming, so let's consider various dimming techniques used in LED color mixing.

A single LED die can only emit monochromatic light. To generate more colors, three primary color LEDs (red, green, and blue — RGB) can be used together for color mixing. Seven basic colors (red, green, blue, yellow, violet, aqua, and white) can be produced just by switching red, green, and blue LED channels. To produce more than seven colors, each LED channel must be able to change in brightness. Dimming an LED channel is achieved by adjusting the current through each LED string. Many colors can be produced by mixing three dimmable strings of RGB LEDs. To change the color temperature of white LED light, a commonly used method is to include a red LED string and vary the brightness relative to the white string to achieve the desired CCT.

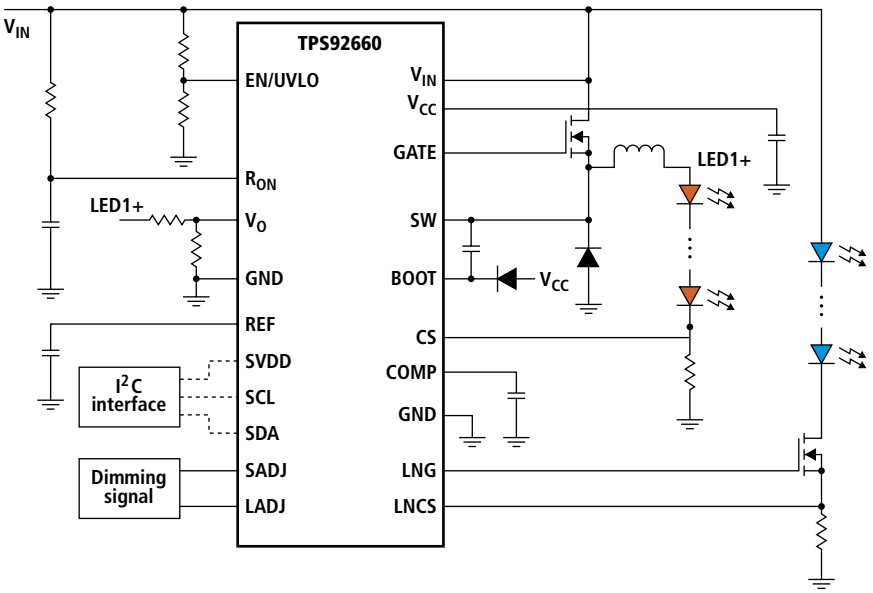

FIG. 1. A two-string dimmable LED driver uses a buck converter for one string and a linear regulator for the second string.

Basically, there are two ways to achieve LED dimming: analog or linear current control and pulse-width modulation (PWM). Both dimming methods change the LEDs' brightness by controlling the average current through the LED string. Both can be implemented in either a switch-mode or linear LED driver. Fig. 1 shows a two-string LED driver containing one buck switcher and one linear regulator, based on the TPS92660. Both LED strings can be dimmed with either analog or PWM techniques. There are advantages and disadvantages to each. In most applications, the dimming method is chosen based on the color mixing performance requirement.

Analog dimming options

You implement analog dimming by adjusting the constant current level through the LED string. Analog dimming can be achieved by adjusting the LED current reference voltage inside the IC, or by adjusting the LED current sense voltage outside the IC. First, let's discuss dimming by changing the LED current reference voltage.

For most LED drivers, including switching regulators and linear regulators, the LED current is determined by the following equation:

$$I_{LED} = \frac{V_{REF}}{R_{SNS}}$$

Where V_{REF} is the internal IC LED current reference voltage and R_{SNS} is the current sense resistance.

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The LED current can be adjusted by changing V_{REF} in some cases. Note that not all LED driver ICs allow users to change the LED current reference voltages. For those ICs that allow the change of the LED current reference, there are generally two ways to do so. The first is to apply an analog voltage on the reference voltage adjust pin provided by the IC. One example is Texas Instruments' LM3409. The user can adjust the LED current by adjusting the voltage on the I_{ADJ} pin. The second way is to adjust the reference voltage through a digital communication interface like I²C. One example is Texas Instruments' TPS92660, which has an I²C interface that allows users to adjust LED current reference voltages through I²C commands.

Another popular way of doing analog dimming is to change the LED current sense voltage. In most applications, the current sense resistor is less than 1 Ohm. It is not practical to change the current sense resistor value by using a potentiometer. Instead, we change the voltage at the IC's CS (current sense) pin by injecting an external DC voltage. Fig. 2 shows a typical analog dimming circuit that works by changing the current sense voltage. The voltage at the CS pin is determined by the following equation:

$$V_{CS} = \frac{R1}{R1+R2} V_{ADJ} - \frac{R2}{R1+R2} I_{LED} R_{SNS}$$

At steady state, the CS pin voltage is equal to the reference voltage. The LED current can be changed by adjusting either the external DC voltage V_{ADJ} or the value of the variable resistor R2.

There is a disadvantage to using analog dimming in color mixing applications. The LED color temperature can change with the LED current. The LED's brightness and color may change during analog dimming, especially when the current change is significant. The system may not generate the desired color under these conditions.

PWM dimming

Pulse-width modulation dimming actually turns the LEDs on and off at a fixed duty cycle and frequency. Assuming the switching or multiplexing is sufficiently fast — typically 200 Hz or greater — the human eye perceives the LEDs to be on continuously.

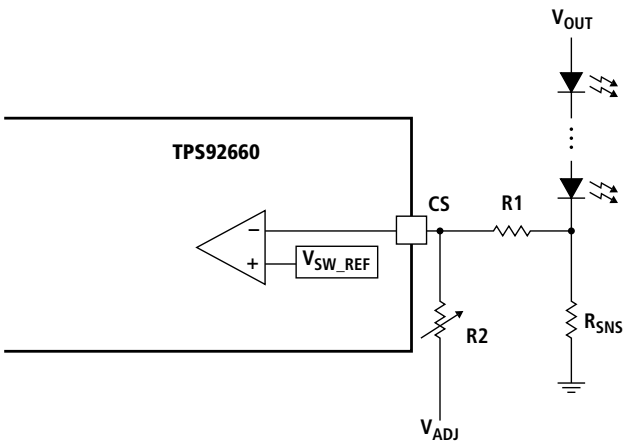

FIG. 2. An analog dimming circuit controls the input voltage to the current sense pin.

The PWM-dimmed LED current is determined by the following equation:

$$I_{DIM} = D \times I_{LED}$$

Where I_{DIM} is the dimmed LED current, D is the on duty cycle of the PWM dimming signal, and I_{LED} is the constant current supplied to the switched LED string.

Many LED driver ICs have a PWM dimming input pin that accepts a PWM dimming input signal generated by a microcontroller. Typically, the driver IC turns off the MOSFET driver only when the PWM dimming signal is low. The MOSFET driver turns back on when the PWM dimming signal is high. The internal circuitry is fully operational during the PWM dimming off cycle. This prevents the IC from restarting, which causes a delay in the PWM dimming rising edge.

For switch-mode LED drivers, a capacitor is typically placed across the LED string to filter out the high-frequency switching noise. This capacitor can slow the rising and falling edges of the PWM-dimmed LED current. So for high-frequency, low-duty-cycle PWM dimming applications, this capacitor needs to be removed. Fig. 3 shows a LED buck regulator PWM dimming waveform without an output capacitor.

Analog-to-PWM dimming

Some LED driver ICs provide a function called analog-to-PWM dimming. The IC's dimming pin accepts the analog signal and converts it to a PWM dimming signal. The PWM dimming frequency is fixed, and the PWM dimming duty cycle is proportional to an input analog signal level.

Analog-to-PWM dimming is very useful in those lighting applications where micro-

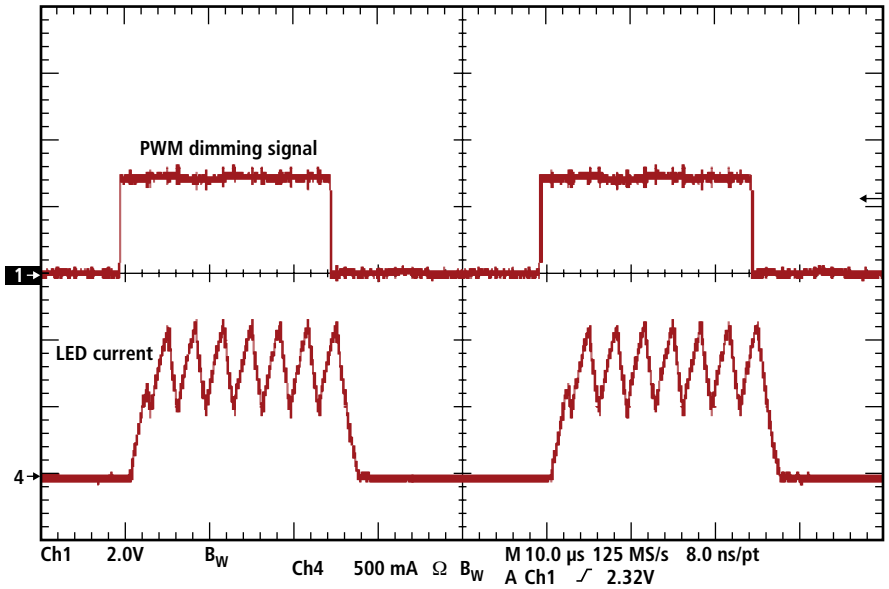

FIG. 3. The PWM signal controls the LED current shown in the bottom waveform.

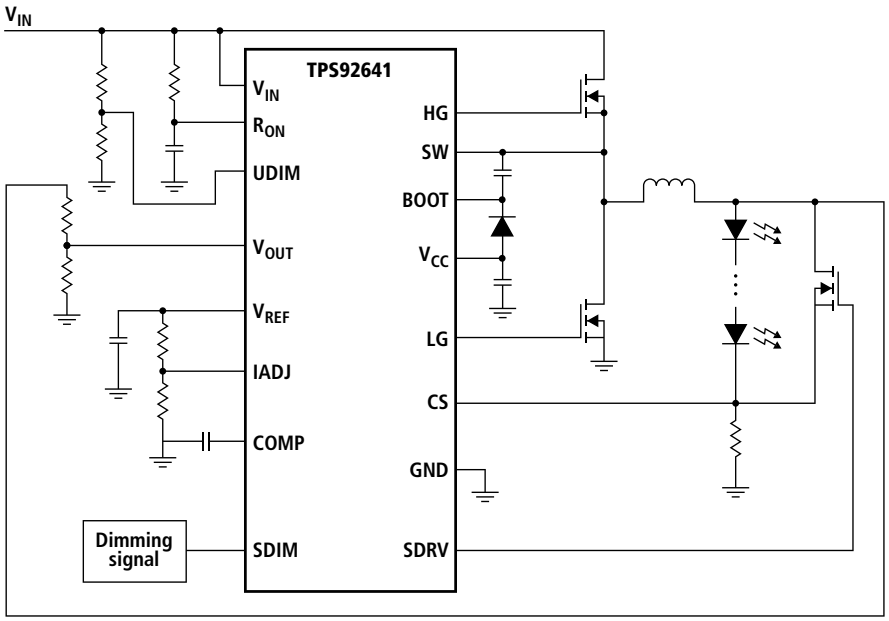

FIG. 4. Shunt FET PWM dimming is implemented with a FET in parallel with the LED string.

controllers are not available. It can also be used to implement the thermal fold back function where the LED current is reduced by PWM dimming when the temperature of the LED board rises above a set point.

Shunt FET PWM dimming

Shunt FET (field effect transistor) PWM dimming often is used for very high-frequency LED PWM dimming. Fig. 4 shows a buck regulator-based shunt FET PWM dimming circuit. An external shunt FET is placed in parallel with the LED string to quickly bypass (short) the converter's output current. The LED string is shut off when the shunt FET is on and is turned on when the shunt FET is off. So the LED string is effectively PWM dimmed by this shunt FET. Some LED driver ICs integrate a MOSFET driver for shunt FET PWM dimming and eliminate the need for an external MOSFET driver.

The switching regulator's inductor current stays continuous during shunt FET PWM dimming. There is no delay caused by inductor current ramping up or down. With a strong MOSFET driver, the shunt FET can be turned on and off at very high speeds. Consequently, the PWM-dimmed LED current has very sharp rising and falling edges. The shunt FET PWM dimming is ideal for high-frequency PWM dimming applications.

There is a disadvantage to using analog dimming in color mixing applications. The LED color temperature can change with the LED current.

Dimming is critical to achieving the desired color and brightness in LED color-mixing applications. There are many approaches to dimming LEDs. The two main categories are analog dimming and PWM dimming. Analog dimming usually can be achieved using a relatively simpler circuit. Analog dimming is generally lower in cost and good for a system where a microcontroller is not available. However, it may not be appropriate for applications that require a constant color temperature. PWM dimming, alternatively, can achieve very accurate color temperature by reducing the color change associated with the LED current level. PWM dimming usually requires an input digital signal generated by a microcontroller — and it increases system cost.

last word

Myth busting as it relates to LED tubes

CHARLIE SZORADI, CEO of INDEPENDENCE LED, states that it's only a question of when the time is right to install LED tubes in place of fluorescents and not if it's the right retrofit path.

Fluorescent tubes have dominated commercial illumination in American ceilings for more than 50 years — more than 2.3 billion tubes are installed, according to the US Department of Energy (DOE). That huge potential retrofit market has drawn the interest of many in the solid-state lighting (SSL) space and resulted in a lot of myths related to LED tube technology. Let's bust some of those myths, considering that LED tubes save 50% or more energy over fluorescent tubes.

To date, the hurdles for adoption of LED tube technology fall into three categories: trust, technology, and cost. Let's explore them, in that order.

Many believe that the LED tube industry has not matured to a trustworthy level, but manufacturers have improved thermal management, and installations now range from Fortune 100 companies to leading health care institutions to leading higher-education institutions. Organizations such as the DesignLights Consortium have qualified LED tubes, and warranties have increased to as long as 10 years on some LED tubes.

Meanwhile, some worry that imported LED tubes lack UL or CE marks or other trusted output testing. Simply ask for source documentation and third-party testing data, and look into LED tubes that are made domestically or that meet the International Class A-10 LED Tube Standards.

And then there are those concerned that new LED manufacturers won't be around to support the warranty. An easy way to protect your business is to look for performance-based programs such as savings shares, lighting service contracts, or LED rental center opportunities. This way you don't fully pay for the technology and aren't chasing the seller if failure occurs.

Let's turn to technology, and the worry that a typical LED tube doesn't give off as much light as its fluorescent counterparts. Fluorescent tubes may have more lumens, but 35% percent of the output is often wasted going up into the fixture. Make sure to look at fixture output side-by-side in foot-candles after a sample LED tube retrofit.

Others worry that an LED tube does not have the same color consistency as a fluorescent tube. Yet the thermal management of many LED tubes has improved to protect the phosphor coating that dictates color temperature. Still others question the quality assurance for LED tubes. The answer is to look for LED tube manufacturers that are ISO 9001:2008 certified.

Then there are those who say LED tubes with external drivers are more difficult to install than internal driver LED tubes. Not so: Installers need to open the cover to the fluorescent ballast in order to install either type of driver system, so the time is roughly identical.

Finally, some contend that the diodes get so hot that they burn out the LED tubes. To combat this, seek out LED tubes with deep-fin, aircraft-grade thermal management and external drivers.

Now let's turn to cost where some argue that specifiers wait to invest in LEDs because of dramatically falling prices. But the cost of waiting, in terms of energy and maintenance, is most likely higher than the price drop, particularly for 24/7 illumination areas. At the least, consider a rolling retrofit where you replace fluorescent tubes and ballasts as they fail with new LED tube technology.

There are other cost-related issues that are top of mind for some specifiers. Those who replaced T12 fluorescent tubes with the better T8 tubes and don't want to upgrade again should still calculate ROI, especially for 24/7 areas. Payback is three to five years, and some worry about warranties in that same range; however, as we mentioned, longer warranties are becoming commonplace.

American-made products are more expensive than imports. Property owners and managers should not focus on the race to the bottom of pricing but instead consider the race to the top of performance. All tubes are not created equal, so look at the equipment and operating cost of a total fixture versus a tube.

It can't be stressed enough that specifiers should find a qualified LED manufacturer and start changing out old fluorescent tube technology in 24/7 areas as soon as possible. Switch to LEDs as fluorescent tubes fail and make a three-year plan to purge your outdated "glass and gas" tubes for toxic-free SSL.

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