SEPTEMBER 2011

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TECHNOLOGY AND APPLICATIONS OF LIGHT EMITTING DIODES

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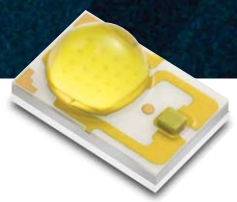

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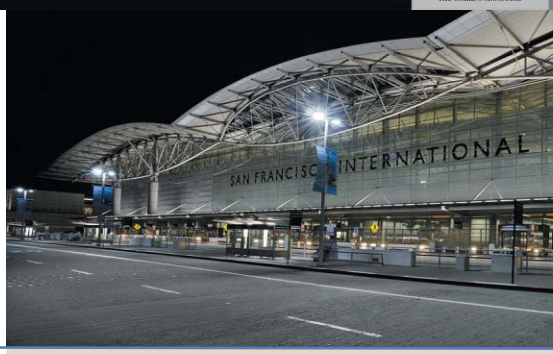
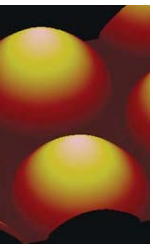


Cover Story

Cree has acquired Ruud Lighting (p.19), which has supplied LED lights for numerous projects, including this one at San Francisco airport.

Photo: © 2011 Ruud Lighting, Inc. – A Cree Company. All rights reserved.



features

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commentary

SSL industry activity fans the flame in a simmering summer

Summer is supposed to be down time, right? We expected that but got a boatload of activity in the LED-based solid-state-lighting (SSL) industry. A major acquisition, activity in the US legislature, and the coronation of the US Department of Energy (DOE) L-Prize winner have stoked the fire recently. And we have a bit of all of the above in this issue.

Let's start with the DOE Bright Tomorrow Lighting Prize (L Prize). Launched in 2008, the program sought to spur SSL innovation to both reduce US energy usage attributable to lighting and to help build an SSL industry in the US. Philips was the only entrant. Still, the company developed what the DOE clearly considers an extraordinary lamp (p.9 and p.21). The DOE's Jim Brodrick went so far as to suggest that the lamp might be suitable for military applications.

In the business sector, LED-maker Cree rocked the SSL segment by purchasing Ruud Lighting and its BetaLED brand (p.19). The two had long been allies with BetaLED using Cree LEDs in a growing family of SSL products. BetaLED has especially prospered in the outdoor-lighting market in street lights and other area-lighting applications. Our cover photo of the San Francisco International Airport is an ongoing SSL project in which BetaLED is involved.

Cree had already entered the system side of the lighting business with the purchase of LED Lighting Fixtures (LLF) Inc back in 2008. But the company has publicly tempered its aspirations in the general-lighting business, repeatedly insisting that its system business was simply focused on symbiotically moving the SSL industry forward, thereby increasing component sales.

Now Cree owns arguably the top dog in the SSL lighting-system industry, especially in outdoor applications, and will find itself in direct competition with other top luminaire makers who are component customers. The company believes the move will accelerate SSL adoption. But surely some customers will see it differently as they compete with a potential supplier.

Action in the courts and financial markets has also been hot throughout this sweltering summer. Osram has bickered publicly with LG and Samsung over intellectual property issues (p.12). In addition, the planned Osram initial public offering may or may not happen given a shaky global economy and slower-than-expected SSL business climate (p.9).

The US legislature, meanwhile, may have boosted the SSL industry by voting not to invalidate prior legislation that mandates mo-efficient lighting (p.10). The H. R. 2417 bill sought to eliminate energy-efficiency requirements that essentially remove incandescent bulbs as an option for general lighting. The US will move into next year with CFL and LED options for 100W-incandescent-replacement applications.

But the fluorescent market is anything other than business as usual. China continues to try and monopolize its supply of rare-earth elements that are a key enabling component of phosphors in lighting (p.16). The move appears to have impacted the fluorescent-lighting business more so than LEDs, although LEDs targeted at lighting also utilize phosphor to convert blue light into white.

Wow what a summer and now we're headed to a very busy fall. We hope to see you at the Strategies in Light conferences in Japan and Europe. And we'll have a report on the annual IES Street and Area Lighting Conference in New Orleans for you in the next issue.

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ProPhotonix Ltd raises cash, targets new LED markets

www.ledsmagazine.com/news/8/7/14

FEATURED *event*

Taiwan LED Lighting Exhibition

October 27-29, 2011
GuSu Gallery, London, UK

The Taiwan Trade Centre in the UK is organizing an LED lighting showcase entitled "Lighting up UK, Switch on to a brighter future!" Not only will this event introduce Taiwan LED lighting products to the UK market, it will also demonstrate how the combination of these products with modern art, decoration and everyday life in the UK creates a totally-unique atmosphere and experience for visitors. Several renowned Taiwanese LED lighting-product suppliers to the UK will showcase various products, ranging from architectural and decorative lighting to industrial lighting. Visitors will be able to understand the quality and creativity of Taiwan LED lighting products as well as experiencing the blending of two different cultures. The event is related to the Taiwan government's drive to become the world's largest manufacturing center for LED lighting, with a target revenue of US$17.5 billion by 2015, creating more than 50,000 jobs along the way.

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For information on more upcoming events, visit www.ledsmagazine.com/events.

ADVERTISERS *index*

Create a Brighter Future

Maxim's LED Drivers Enable Drop-In Replacements for Offline/MR16 Lamps

Maxim's solutions for dimmable offline (A, R, PAR, GU10, etc.) and MR16 LED retrofit lamps use a proprietary architecture to achieve flicker-free operation with dimmers and electronic transformers. This ensures compatibility with the existing electrical infrastructure, helping manufacturers overcome a critical obstacle to large-scale adoption.

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news views

LAMPS

Philips wins L Prize for 60W-replacement LED lamp

Philips Lighting North America has won the US Department of Energy (DOE) Bright Tomorrow Lighting Prize (L Prize) competition in the 60W-replacement-lamp category. The Philips LED-based lamp has undergone 18 months of vigorous lab and field testing, including having 1300 lamps installed around North America in real applications. Philips has already collected the $10 million prize for its lamp, which has an output of 910 lm at 9.7W, corresponding to an efficacy of 93.4 lm/W. The correlated color temperature is 2727K, and the color-rendering index is 93. As well as the cash, Philips will also be able to participate in Federal procurement contracts and energy-efficiency programs, which could prove to be even more valuable over the longer term. Philips has said that its lamp "could arrive in stores as soon as early 2012."

The *LEDs Magazine* opinion piece on the L Prize (www.ledsmagazine.com/news/8/8/11) questioned whether the competition can be considered a success, or a worthwhile use of taxpayers' money. On page 21, we discuss the L Prize in detail with both Philips and the DOE. ◄

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

BUSINESS

Osram IPO under threat

In March this year, Siemens AG announced plans for an initial public offering (IPO) of shares in Osram GmbH, its lighting subsidiary (www.ledsmagazine.com/news/8/3/30). The IPO was scheduled for this fall, but recent press stories suggest that Siemens may change its plans. Weakness in both the lighting and equity markets may have significantly lessened the potential IPO value. Analysts that had valued Osram as high as EUR 6 to 8 billion ($8.6 to $11.4 billion) now expect a drop in valuation of as much as 35%.

William Mackie, senior analyst, capital goods at Germany-based Berenberg Bank, has followed the situation and sees two main reasons for the IPO. He said it would "enable Osram to develop a more entrepreneurial approach to grow the business in the face of the changing business model within the lighting industry." And he said the spinout would allow Siemens to focus on its "core activities in energy, industry, and healthcare."

When asked if he thought the IPO would go forward as planned, Mackie said, "Under the current market conditions, the likelihood of the IPO proceeding this fall has significantly decreased. We believe Siemens continues to prepare for an IPO and »page 10

LAMPS

Cree buys Ruud, shows 152 lm/W prototype LED lamp

In mid-August, Cree effectively increased the proportion of its sales coming from LED lighting systems versus components with its acquisition of Ruud Lighting. The $525 million deal includes Ruud's LED brand, BetaLED, which is an established presence in the LED outdoor-lighting field. The deal is discussed in more detail on page 19.

Cree already sells lighting fixtures via the former LLF, Inc, which it acquired over 3 years ago. To date, it has not launched any A-type LED replacement lamps, but has unveiled details of several prototype lamps that serve as technology demonstrators. The latest is a lamp that delivers 1330 lm and consumes 8.7W, with an efficacy of 152 lm/W.

Cree says that the prototype "exceeds the performance goals" of the DOE's L Prize competition in the 21st Century Lamp category. This third L-Prize category (the first has just been won by Philips) has not been officially »page 10

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Osram from page 9

will make a final decision in the next 2-3 months."

The drop in valuation has two main causes; first is that the global economy is on a shaky footing. And second, the LED and SSL business is less robust than many expected for this year. The demand for LED-backlit TVs was lower than many LED manufacturers expected and many LEDs originally destined for that market have been sold at bargain prices into general-illumination applications – even though those LEDs may be less than ideal for general illumination. There is also increasing price pressure on both LED components and SSL luminaires caused by new players in Asia.

One option is simply waiting for the market to improve, and Mackie expects another upwards cycle. "I certainly expect another upturn in demand to emerge as adoption of LED lighting solutions in the general-lighting market develops, although this is likely to occur at lower price points," he said. "In the traditional lighting technologies, the lighting manufacturers are also currently being impacted by a sharp increase in prices of rare-earth metals which is denting profitability. Siemens may indeed wait for these two factors to pass and then proceed with an IPO under better conditions." ◄

MORE: www.ledsmagazine.com/news/8/8/28

BUSINESS

GE acquires Lightech, invests in Nuventix

GE Lighting (NYSE:GE), a lighting manufacturer based in East Cleveland, OH, has signed an agreement to acquire Lightech (Tel Aviv, Israel), a privately-held manufacturer of LED electronic drivers and halogen transformers for the lighting industry. Terms of the transaction were not disclosed (www.ledsmagazine.com/news/8/7/22).

GE says that the acquisition of Lightech will accelerate the lighting company's capability to provide integrated lighting and power-supply products. "Lightech's reputation for high-quality, innovative designs and skilled engineering complements and expands [our] team of engineers and scientists around the world," said GE Lighting president and CEO Maryrose Sylvester.

Cree from page 9

launched, but legislation states that the requirements include 1200-lm output at more than 150 lm/W, with >90 CRI, CCT between 2800K and 3000K, and a lifetime over 25,000 hours.

The new lamp looks significantly different than most LED retrofit lamps, and decidedly different from a traditional incandescent bulb. Issues might arise due to the lamp's cylindrical optical element, which will not provide an omnidirectional distribution of light, and also the relatively large heatsink. Gerry Negley, Cree's CTO and co-inventor of the bulb, said, "I don't know what lighting will look like in the 21st century. I can tell you it will not be constrained with shapes and technology of the past. It will not look like a traditional light bulb." ◄

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

Separately, GE's Ecomagination Challenge fund was one of the participants in a $10 million funding round closed by Austin, TX-based Nuventix, a maker of LED cooling components. GE has also entered into a license agreement to access the patent portfolio surrounding Nuventix's SynJet technology, which GE Lighting's scientists see as an enabler of broader and faster LED-module adoption. SynJet active-cooling technology can be incorporated with commercially-available light engines such as GE's Infusion LED modules, and is compatible with a wide range of lighting-fixture types. ◄

MORE: www.ledsmagazine.com/news/8/7/20

LEGISLATION

US House votes down incandescent bulb-ban bill

In mid July, the US House of Representatives failed to pass the "Better Use of Light Bulbs Act," which aimed to repeal lighting-related sections of the 2007 Energy Independence and Security Act (EISA) legislation. The vote was targeted at nullifying sections of EISA that will effectively ban certain types of lamps, beginning next year.

The bill (H.R. 2417) was proffered by the Republican party, members of which believe the government has no place legislating what type of light bulbs citizens buy. The bill failed to achieve the two-thirds vote required, although a majority voted in favor.

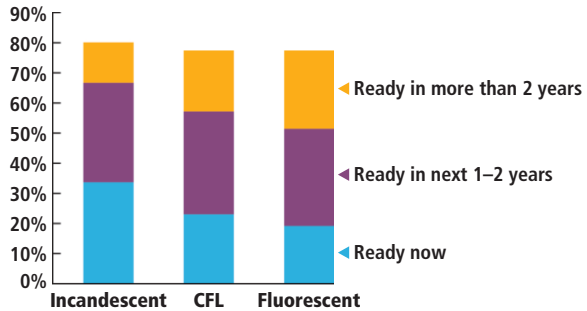
EISA legislation requires that from January 1, 2012, 100W lamps, or more specifically lamps with a light output of around 1700 lm, operate 30% more efficiently. In successive years the efficiency requirements will be applied sequentially to 75W, 60W, and 40W lamps. While EISA doesn't specifically ban incandescent lamps, in reality only certain technologies – including SSL – will be able to meet the requirements. ◄

MORE: www.ledsmagazine.com/news/8/7/12

LIGHTING

LEDs may be reaching "tipping point" with electrical contractors

Electrical contractors may soon reach the point where specification and installation of SSL, where appropriate, becomes the rule and not the exception. Results of a survey of 700 readers of *Electrical Contractor* magazine indicate that a majority of electrical contractors believe LED lamps are now ready to replace incandescent and fluorescent lamps – or soon will be. John Maisel, publisher of *Electrical Contractor*, said, "The more we educate [electrical contractors]



Market readiness for LEDs to replace different types of lighting technology. Source: *Electrical Contractor.*

news+views

on the technology and opportunities in the multi-billion dollar LED market that's growing more than 30% per year, the greater value they bring to their customers."

Among those responding to the survey, 33% said LEDs are ready now to replace incandescent lamps, compared with 23% and 19% saying LEDs are ready to replace CFLs and fluorescents, respectively (see chart, page 10).

An additional 33% said LEDs will be ready to replace these traditional lamp sources within the next 1-2 years. Of those who said LEDs were not ready or who didn't know when LEDs would become viable, 19% said that high cost was a factor, while 10% mentioned the need for performance improvements. ◄

MORE: www.ledsmagazine.com/news/8/8/16

RETAIL LIGHTING

Retail shoppers respond to lighting with superior color rendering

Would you buy a shoe based on the way its color is rendered? A new research study says you just might. San Jose, CA-based Xicato, a manufacturer of LED modules, commissioned a study from independent researcher Colette Knight in order to evaluate the effect of lighting quality on the attraction towards, appreciation of, and sales of, merchandise.

The experiment found that shoppers and lighting designers were more attracted to retail shoe displays that used spot lighting with better color-rendering ability, in particular enhanced rendering of deep reds.

The experiment was performed at House of Fraser, a retail store in London. Three identical alcoves were illuminated with halogen lamps, Ra=80 LEDs (R9=16) or Ra=95+ LEDs (R9>95). The LED sources were based on Xicato's Standard modules for Ra=80 and the Artist Series modules for Ra=95.

Shoppers and lighting designers were asked to rate the effectiveness of the lighting in terms of grabbing attention and making the shoes stand out. A statistically-significant lower rating was given to Ra=80 LED sources, compared with the halogen and Ra=95 LED sources, highlighting the importance of color rendering. ◄

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

LED LIGHTING

LG Innotek walks-the-walk with huge LED production plant

LG Innotek, a vertically-integrated manufacturer of LEDs for displays and lighting, has installed over 10,000 LED luminaires in what it is claiming is the single-largest LED production complex in the world. The facility in Paju, Korea is 182,000 m^2 in size, comparable to 26 football fields.

The Paju complex, which includes the manufacturing facility, administration

buildings and associated infrastructure, began operations in July 2010. Under one roof, the company performs all aspects of LED production, from epitaxial wafer growth (some of which is on 6-inch wafers) to production of LEDs for lighting and LED modules for backlighting units. The facility has a targeted production level of 1.8 billion LED units per month.

The Paju LED installation uses various high-efficiency LED modules including LG Innotek's ModuleA planar panel lighting module and ReflectA reflection-type lighting module. ◄

MORE: www.ledsmagazine.com/news/8/7/23

PATENTS

Osram extends LED patent battle against Samsung and LG

Germany LED and lighting manufacturer Osram has filed a complaint against LG Innotek with the Korea Trade Commission (KTC) alleging that the LG subsidiary is infringing four Osram patents focused on white LEDs. Meanwhile, Samsung LED has asserted that Osram has infringed eight Samsung patents, citing a number of Osram's most popular LED product lines including Dragon and Oslon.

Osram instigated the first steps in this skirmish back in June when it targeted

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Samsung and LG with LED patent litigation in the US, Germany, and Japan. Samsung responded almost immediately with a counter suit against Osram filed in Korea. And subsequently LG filed a complaint against Osram in Korea, while Samsung and Osram both took complaints to the US International Trade Commission (ITC).

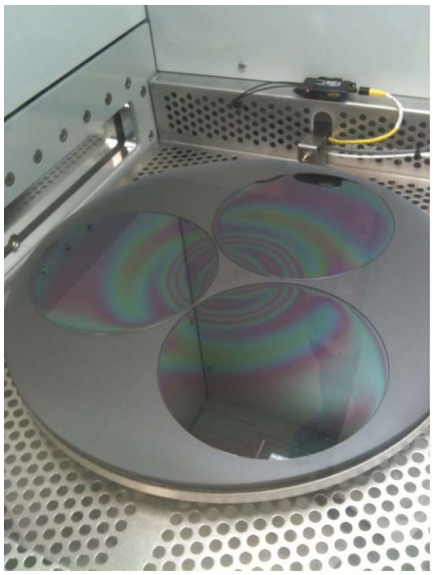
In the latest action, Osram has asked the KTC to issue an order banning the export of certain LG products such as LED-backlit TVs and computer monitors. Osram is also seeking to have some of its rivals' patents declared invalid. Although there is plenty of activity, this seems to be a normal series of actions and reactions as the companies seek to protect their patent portfolios. Cross-licensing agreements are the likely outcome. ◄

MORE: www.ledsmagazine.com/news/8/8/31

LED FABRICATION

Bridgelux hits 160 lm/W in lab with GaN-on-silicon LEDs

LED maker Bridgelux says it has fabricated LEDs in the lab using gallium-nitride-on-silicon (GaN-on-Si) technology that delivers 160 lm/W (cool white) and 125 lm/W (warm white) efficacy. These values, achieved using 8-inch silicon wafers, (see photo) are on a par with LEDs produced on sapphire.



Bridgelux believes the GaN-on-Si approach will ultimately yield a "75% improvement in cost" for LED components that will in turn reduce the cost of LED-based lamps and luminaires. The company also said that its 1.5-mm blue LEDs can deliver wall-plug efficiency as high as 59% at 350 mA.

Using silicon wafers would allow both lower baseline wafer costs and significant back-end manufacturing cost savings. In front-end manufacturing, thermal mismatch between the GaN and silicon layers has been a challenge for epilayer growth processes. Bridgelux claims to have solved this problem by using a proprietary buffer layer. Bridgelux's Long Yang, VP of chip technology, said that the MOCVD steps represent 40% of the capital expenditure in an LED fab line. Bridgelux is scheduled to deliver its first commercially available GaN-on-Si product within two years. ◄

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

CONTROL

Acuity buys Horizon Control

Acuity has added to its long list of lighting brands with its cash acquisition of Horizon Control, a company that has focused on PC-based lighting-control systems for applications such as entertainment and architectural lighting. Acuity chairman, president and CEO Vernon Nagel said, "The rapid expansion of LED lighting and other emerging technologies makes integrated lighting control increasingly pivotal in our ability to deliver high-quality, customer-focused solutions." He noted that while Horizon's products are not limited to use with LEDs, clearly SSL is an important strategic direction for the application of controls. Acuity paid an undisclosed amount of cash, and will employ Horizon's entire workforce. ◄

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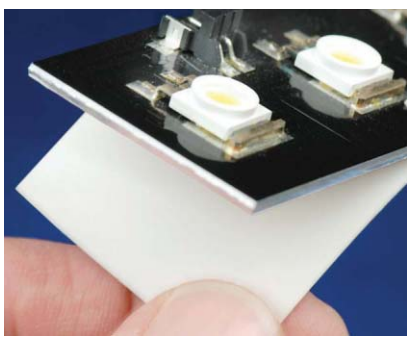

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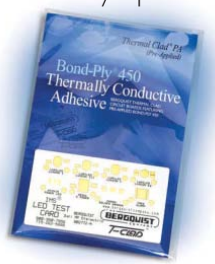

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MATERIALS

Rare-earth supply constraints escalate

MAURY WRIGHT

Rare-earth elements are critical enabling technologies in lighting as well as many other applications including LCDs and automobiles, and China continues to try and capitalize on its present supply monopoly. In lighting, rare-earth elements are broadly used in phosphors for both fluorescent lighting and LED-based solid-state lighting (SSL). The Chinese government has recently tightened quotas on the materials and that has some industry watchers concerned about the impact on prices and components.

We covered the China quota situation and offered some insight into how rare-earth elements are used in LEDs back in February (www.ledsmagazine.com/features/8/2/7). Since then, China has further tightened the supply. Technically China didn't reduce the quota for exports but rather in May ruled that ferroalloys containing more than 10% rare-earth minerals will now be included in the existing quota. Essentially they reduced the export supply, and that has concerned some in the lighting industry.

Fluorescent impact

The impact on fluorescent lighting might potentially be greater than the impact on LEDs. Linear-fluorescent lamps, for example, are phosphor coated on the inside of the glass. Julian Carey, director of product marketing at phosphor-specialist Intematix, said, "Gram per gram, LEDs use a lot less rare-earth material than fluorescent."

Tighter exports, however, still might not have a major impact on fluorescent lighting. The quota only applies to the raw material. Products that use rare-earth elements and that are manufactured in China aren't subject to the quota so long as the rare-earth material constitutes 40% or less of the value of the product. And the bulk of fluorescent lamps are already manufactured in China, and aren't subject to the quota.

Still, the tighter export supply caused fluorescent-lighting prices to rise over the course of the summer. In mid August, the National Electrical Manufacturers Association (NEMA) said prices had escalated 24% or more.

The news also led GE Lighting to develop a web page called "Understanding rare earth metals" (www.gelighting.com/na/business_lighting/education_resources/rare-earth-elements/) dedicated to the subject. The site includes background on the science and what GE called the "crisis," as well as links to many media reports on the topic.

LED impact

Even though LEDs use far less rare-earth material, generally to convert blue light to white, the quota could still potentially impact price or supply. But no one in the LED industry seems overly concerned.

"This is another area where LEDs have an enormous advantage over traditional lighting," said Michelle Murray, head of corporate communications at Cree. "While LEDs do contain small amounts of rare-earth materials, the amounts are so small compared to traditional lighting that we have seen and anticipate almost no impact on our supply chain. We continue to monitor the situation."

Intematix also asserts that its business model will ensure that it can supply phosphor to its LED customers. The company has manufacturing operations in both the US and China. The phosphors manufactured in China meet the requisite of less than 40% of the value being the raw rare-earth material, so Intematix can export those phosphors independent of the quotas.

It could be that the impact on the SSL market from the tighter supply of rare-earths is positive. Higher fluorescent prices could make SSL a more affordable option. More likely, the rare-earth quotas will impact other applications more significantly than lighting. ◄

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BUSINESS

Cree acquires Ruud Lighting and BetaLED subsidiary

The cover of the May/June 2007 issue of LEDs Magazine featured a large photo of an outdoor LED lighting fixture from BetaLED, linking to our report from the Lightfair 2007 tradeshow. This discussed, among other things, BetaLED's launch of its LED fixtures, as well as the indoor LED lighting products launched by LLF, Inc. Now, following Cree's acquisition of Ruud Lighting (BetaLED's parent) for an estimated net cost of approximately $525 million, both LLF and BetaLED are part of Cree's lighting division (Cree acquired LLF in early 2008 – see www.ledsmagazine.com/news/5/3/5).

So is Cree still an LED maker, or is it becoming a lighting company? LEDs Magazine asked Chuck Swoboda, CEO of Cree, how the company should be described. "We're an LED lighting company," he said. "This hasn't changed." However, it's clear that the proportion of lighting products versus LED components has changed.

Because the Ruud deal is already finalized, the company's revenue will be added to Cree's balance sheet right away. Taking a snapshot of the current position (without factoring in any growth), we estimate that lighting now represents about 20-25% of Cree's revenue, while the LED components segment represents a further 65-70%. (For more on this, see the "Number crunching" section below).

Of course, Ruud was originally a "traditional" – by which we mean "non LED" – lighting company, but through its BetaLED product line, the company was one of the first to transform the majority of its business to LED-based systems. The BetaLED launch at Lightfair 2007 was the result of Ruud having built a dedicated team to focus on LED products. Cree and BetaLED have been working closely together for around 6 years. Swoboda said that more than 60% of Ruud's business is now LED based, and that the LED side of the company grew by 50% last year. "100% of their investment is in LED development," Swoboda said. "They are building [LED-based] products that make traditional products obsolete."

So what are the benefits of the deal? Well, obviously Cree has bought a successful company and brands, and gains a much broader range of both LED and other lighting products. Both companies will benefit from the combination of their technology, their products and brands, and their sales infrastructure.

But as well as selling BetaLED's products, Cree also wants to sell more LEDs, and not just internally via BetaLED. A phrase used several times by Swoboda was that the deal will "accelerate the adoption of LED lighting." In Cree's view, the deal will help Cree to "drive the market," creating and expanding opportunities for LED lighting. "We are still at a very early stage of penetration; LEDs are a tiny percentage of the overall market," said Swoboda. "We still have to keep proving the benefits of LEDs."

The reasoning appears to be that the combined Cree-Rudd can do a better job of building a market for LED products (both systems and components) by competing effectively with traditional lighting companies. "We see our competition as companies using technologies like metal-halide lamps. This is our focus," said Swoboda. "We don't have a legacy lighting business to protect."

Accelerated adoption

Cree also uses the reasoning that the LED lighting market is not moving fast enough by itself, and needs stimulation in the form of companies that can demonstrate and supply suitable LED-based components and systems. By "accelerating the adoption" of LED lighting, this benefits the market as a whole, i.e. not just Cree but also its LED-focused competitors. Similar reasoning was used (at the component level) when Cree first launched packaged LED products more than seven years ago (www.ledsmagazine.com/features/1/9/3).

Swoboda said that a combined component-system approach to the market, which Cree has employed since it bought LLF, can be very beneficial. "We gain additional knowledge [about the lighting systems market] and understand customer requirements," he said. "This helps us build better components."

However, it seems reasonable to ask whether there will be concerns about the deal among luminaire makers who buy LEDs from Cree and compete directly with BetaLED. Will these luminaire makers still want to share their market knowledge with Cree? Perhaps some will be concerned with supply issues and the availability of the best-performing/newest components. (Of course, similar issues are always raised when this type of acquisition or merger occurs).

BetaLED's widely-deployed LEDway street light.

Swoboda acknowledged that there may be an "emotional" reaction, at least initially. "However, we think that customers will still want to use the best LEDs," he said, adding his opinion that Cree's track record as a component supplier will speak for itself. "Our clear strategy is that the component business has to enable our customers to be successful."

He also pointed out that many of Cree's competitors – Philips, Osram, Zumtobel, a number of Chinese manufacturers – have a large degree of vertical integration within their organizations.

So, this appears to be Cree's big challenge, now that it has become vertically integrated to a greater extent – to grow the Ruud/BetaLED business, while also maintaining its position as one of the leading suppliers of LED components. To do this, it may have to work hard to placate some of its customers, according to some of the comments added to our news item announcing the deal (www.ledsmagazine.com/news/8/8/26). "I wonder how many fixture companies will reconsider using Cree LEDs in their products, to avoid supporting a competitor," said one. Another said that the deal "has caused

news+views

a huge level of discontent and bad feeling in multiple OEM boards." The same comment said: "I don't know of one US lighting manufacturer's president that is happy with the previous LLF arrangement. This new move is bound to enhance that mood of discontent dramatically and in my opinion will probably generate a significant push-back by year's end."

Number crunching

For its fiscal year 2011, ended June 26, 2011, Cree reported total revenue of $987.6 million, which represented a 14% increase compared to revenue of $867.3 million for fiscal 2010. Of the FY2011 total, around 90% (approx. $890 million) was from LED products, with the rest from power and RF products. Within LED products, revenue from LLF was around $80 million.

Because the deal has already closed, Ruud will contribute about $20 million in revenue to Cree's balance sheet for the remaining 40% of the current quarter. So for the purposes of this snapshot calculation, we can extrapolate this figure to $200 million annually. Of course this does not include any growth (or decline).

The combination of LLF and Ruud is worth around $280 million, from total revenue of around $1.2 billion, which allows us to estimate that Cree's lighting business represents about 20-25% of the company's revenue. In comparison, the LED components segment represents a further 65-70%.

funding + programs

Philips wins L Prize for 60W-replacement LED lamps

MAURY WRIGHT

After 18 rigorous months of testing Philips' candidate LED lamp, the US Department of Energy (DOE) announced on August 3 that Philips has won the Bright Tomorrow Lighting Prize (L Prize) competition in the 60W-replacement-lamp category. Philips is busily preparing the lamp for production and sale late this year or early next.

L-Prize lamps were tested in a variety of locations, including these "wedding cake" lights in the Merchandise Mart in Chicago. Source: DOE.

The DOE launched the L Prize competition in 2008 to encourage the development of more-efficient SSL products and help build a US LED lighting industry (www.ledsmagazine.com/news/5/12/11). Philips was the only company to enter the contest and submit lamps for testing, although earlier this year Lighting Science Group (LSG) and GE Lighting submitted letters of intent to enter. Originally the contest was to have three categories – 60W replacement, PAR38, and 21st Century lamp – but the PAR38 contest is on hold and the 21st Century lamp category was never formally launched.

Still, the 60W-replacement category was clearly the prime focus as that's the most widely-used incandescent lamp and therefore provides the greatest potential for energy savings. Moreover the DOE put the largest prize – $10 million, purchase guarantees, and explicit promotion of the winner – on the 60W category. The contest came with stringent performance requirements, and Philips delivered the winner with specs exceeding those requirements, including 910-lm output at 9.7W, corresponding to 93.4 lm/W efficacy (www.ledsmagazine.com/news/8/8/8).

Philips was naturally delighted at the announcement – see "Philips savors L Prize" column at right. We also had the opportunity to discuss the L Prize program with DOE SSL Program Manager Jim Brodrick, in the following Q&A session.

LEDs Magazine: Did the DOE achieve its goals with the L Prize program?

Jim Brodrick: Oh yes. Of course, there is more yet to come as Philips gets something on the market. Philips put a lot of time and money and talent into doing this. They went after this very difficult challenge to move the technology envelope. It's definitely an achievement considering that they submitted this in the fall of 2009. » page 23

Philips savors L Prize, plans product launch

Philips won accolades and cash in the L-Prize contest, but the big win may come in market success. Indeed the company said it spent significantly more than the $10 million prize developing the L-Prize lamp that it now will put into production.

Did Philips get what they hoped for out of the contest? "Absolutely," said Silvie Casanova, senior communications manager for Philips Lighting North America. "For us this was great. It pushed the boundaries for us. We're proud to be the first and only company to actually have submitted LED bulbs in the 60W L-Prize competition."

Upon winning the contest Philips said it would bring the product to market early next year but since has said that it hoped to sell the lamp late this year. Casanova confirmed that goal, but the commitment remains next year.

We at LEDs Magazine questioned the delay (www.ledsmagazine.com/news/8/8/11) given that a manufacturing plan was a requirement of the contest. But apparently Philips hadn't moved on the actual manufacturing and marketing effort prior to the announcement of the win.

Still, Casanova points out that Philip's existing 60W-replacement lamp, which is sold as the EnduraLED 12W to commercial customer and as the Ambient LED 12W to consumers, was enabled in part by the contest. Casanova said, "What we learned from the L Prize development has been built back into our 60W and 75W LED lamps and actually allowed us to bring those to market faster and to use proven technology."

L Prize vs EnduraLED

What are the differences in the products? The existing 60W that's on the market was built to meet Energy Star requirements, said Casanova: "The L Prize bulb all around is an improvement. The L Prize had to meet » page 22

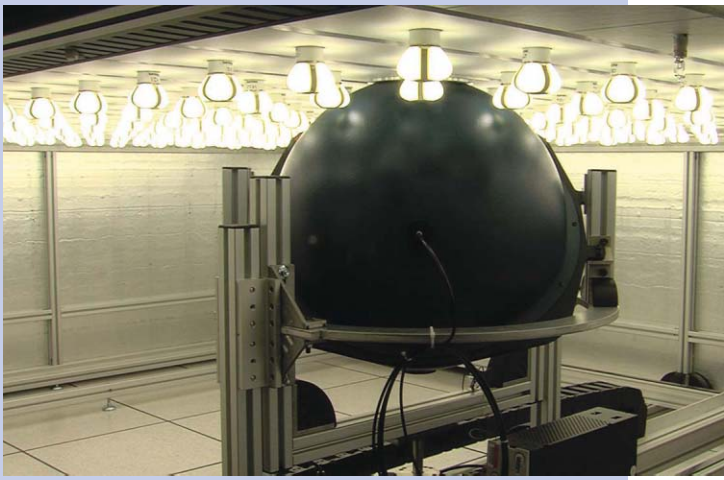
funding + programs

Philips savors L Prize from page 21

higher standards than Energy Star."

The L-Prize candidate lamp utilized four illumination chambers separated by air-cooling channels whereas the EnduraLED products use three. But the production version of the L-Prize lamp will use the three-chamber design, according to Casanova. Also, the original 9.7W L-Prize lamp contained 24 LEDs whereas the 12W lamp has 18. In production, Philips will use an 18-LED design for the L-Prize lamp enabled by advancements in LED brightness and efficacy.

Geometrically, the EnduraLED and L-Prize lamps are virtually identical. The L-Prize lamp lacks the visible cooling fins that are present on the EnduraLED products, suggesting



Lab testing of Philips' L-Prize lamps. Source: DOE.

a more-advanced thermal design and/or brighter LEDs that can be operated at lower drive current. The L-Prize lamp is also lighter than the EnduraLED.

Price and US manufacturing

There were questions in the aftermath of the winning announcement as to whether the DOE could pay the $10 million prize given the US budget crisis. But Casanova confirmed that Philips received the money and said, "We're going to take that and reinvest it into manufacturing the bulb here in the US and marketing it here in the US."

In the end, Philips was alone in entering the L Prize. Without commenting directly on the lack of other entries, Casanova described how Philips was able to meet the challenge. "It speaks to our LED leadership and the capabilities that we have across all of our different sectors across lighting," she said, adding that Philips' Lumileds LED business, its Lighting Systems and Control business, and its Color Kinetics systems business all contributed to the L-Prize lamp design. Few if any other companies have such a broad array of resources to collaborate on a design. Casanova concluded, "We had the breadth and the depth needed to create this bulb." ◄

funding + programs

Philips wins L Prize from page 21

This has raised the competitive bar. All of the other companies are looking at this and they want in. They want something in that competitive zone. The ante is up, and the competitors are responding.

From the DOE perspective, we want to save energy and save the consumer money. With this very high efficacy lamp there is a lot of energy and money to be saved.

You have a new consumer option. Boy, there has never been something quite this efficient that looks and operates just like an incandescent lamp except for two things: 25,000-hour life and 90 lm/W efficacy. That means you are going to have about 10W – actually a pinch less – in that socket. You are opening up a new paradigm. You may well screw this into a socket and never remember the day or the year that you installed it. Lighting moves into a new zone.

And last but not the least is US jobs. They are going to manufacture this right in the US. What's not to like?

Did you expect more companies to enter the contest sooner or did you know that you set the bar so high that it would be tough for anybody to enter?

We originally designed the contest and we wanted more of a horse race, sort of get everybody involved. But then it became a little obvious that this was so darn high that it was going to be very difficult to do. You have to have the right mix of people and capabilities to enter the contest as early as Philips did. We hoped for one way and it didn't quite work that way. But we sure have a great lamp coming out of the contest.

LSG and GE submitted intentions to enter. And the DOE had said that as many as three companies might ultimately be judged to have met the entry requirements and therefore be eligible for promotions even though only one would receive the cash prize. Do you expect LSG and GE to follow through and submit samples for testing?

We've closed the contest completely. We won't be doing any testing. That doesn't mean that LSG and GE can't continue and put their bulb out on the market. I hope they do. But the A19 60W replacement contest is completely closed.

Rumors suggested that the DOE couldn't pay the cash award, given the US budget situation. Could you comment on that?

The $10 million was paid within 24 hours of the award. We're looking for them to set up the manufacturing and start to produce the lamp. We'd like to see lots of sales.

We were a little bit surprised that they wouldn't be manufacturing it a bit sooner. Was there any requirement that they have the lamp ready for market to be judged the winner?

They were asked to submit a lot of material on their manufacturing capability and plan so that we could see that at least 75% of the content or the assembly cost is based in the USA.

Keep in mind that they have the Endura-

LED 60W lamp on the market. And some of the technology in the EnduraLED lamp came out of this L Prize program. So a byproduct of the contest is that it got another product on the market, maybe not as powerful as the L Prize, but that's a full equivalent 800 lm.

Did you have any preconceived notion about the look of the lamp? Some companies have said they want to bring lamps with a traditional look to the market whereas the Philips lamp looks quite different – especially with the yellow remote phosphor evident in an unlit state.

Geometrically the shape, the screw base, the quality of the light [are the same]: the only two things that are different are the 90 lm/W and the 25,000 hour life. The appearance of the lamp when it's off, I don't know, it may be something that some people find a little bit odd. I'd guess that a lot of people thought those flat-screen TVs looked a little odd when they first bought them.

What was the testing process like and how did the lamp perform?

We ran through a whole lot of testing. It fulfilled all of our requirements. The stress tests were amazing. You could imagine that this could go into military applications. We put it through heat, cold, vibration, and really bad quality electric – 45 cycle and 120 cycle. It's very solid.

What about the field testing?

Our L Prize partners, 14 from our utility partners, put them right into field applications. One of the interesting ones was the Merchandise Mart in Chicago. They had these wedding-cake lights (see photo, page 21) that were on a 12-foot ceiling. They had eight 60W incandescent lamps in there and they had to de-lamp because the L-Prize entry only needed five.

Will the PAR38 and 21st Century lamp portions of the L Prize contest go forward?

It's in discussion here at the DOE. We're looking at the best path to go forward. We've got to talk to upper management. And realize that the market isn't sitting still. Other screw-in lamps are coming that are performing better and better.

That implies that you need to set a tougher challenge: don't you have the freedom to set new, more stringent requirements?

Keep in mind that the legislation sets some of those numbers. Good or bad we can't deviate from those. ◄

Skepticism continues over LED T8 replacements

Over the summer, the US Department of Energy (DOE) released two new publications that again question whether LED-based linear lamps can be a cost-effective replacement for T8 and other types of fluorescent lamps. The DOE's round 12 results of its Caliper (Commercially Available LED Product Evaluation and Reporting) testing program revealed marginal improvement when LED T8s are used in the right fixture. The DOE also published results of one of its Gateway trials that was focused on LED T8s, and which also revealed sub-par performance for SSL lamps.

The linear-fluorescent-replacement market continues to entice makers of SSL lamps. The market might be the single largest for LED retrofits if SSL technology could offer suitable light output and better efficacy. But there are numerous technology hurdles for LED linear lamps, which aren't inherently omnidirectional like fluorescent lamps. The directionality of LED, which is a benefit in many applications, is not a good match for the design of fluorescent troffer fixtures. LED T8s don't now produce lumen output on par with the fluorescent lamps. And fluorescent technology has made great improvements, especially in efficacy. For more background on LED T8s, see www.ledsmagazine.com/features/7/6/6.

In Caliper round 12 testing (www.ssl.energy.gov/caliper.html), the DOE didn't evaluate any new T8 lamps, but rather tested the two best-performing lamps from prior-round testing in high-performance troffers with prismatic lenses. Previous testing had been done primarily in parabolic-louvered troffers, and the louvers have proven to be a mismatch with directional LEDs.

Testing in high-performance troffers still revealed a basic problem of inferior light output: the LED lamps delivered about half the light output of the reference fluorescent lamps. Despite the fact that SSL lamps generally use less power and offer greater efficacy, light output remains an issue especially in a retrofit scenario with one-for-one lamp replacements.

The LED lamps did perform well in terms of spacing criteria (SC), matching the fluorescents and achieving good and uniform light distribution in the lensed troffers. Given that the fluorescent lamps are brighter, this may seem counter-intuitive. But as Heidi Steward, research engineer at the DOE's Pacific Northwest National Laboratory (PNNL), explains, "Spacing criteria is a measure of evenness of light pattern on a surface below the luminaires – usually the work plane. It is not a measurement for lighting levels." Simply put, the fluorescent-lit room would be brighter, even though the LEDs would offer acceptable uniformity.

In many cases, fluorescent-lit spaces are overlit, and Steward agreed that LED T8s might be a plausible option in such a scenario. But cost remains a huge issue. The DOE has said that no SSL T8 tested to date would provide payback in 50,000 hours of use based on energy and maintenance savings.

SSL T8 Gateway test

The Gateway "Laboratory evaluation of LED T8 replacement lamp products" report (www.ssl.energy.gov/gatewaydemos.html) presented similar findings, albeit in far greater detail. The study was performed by the DOE, PNNL, and the Lighting Design Lab, in the latter's Seattle, WA, facility. The project included testing of four different types of troffer fixtures, three LED T8 lamps, and T8 and T12 fluorescent lamps.

The researchers created a test space with four troffers mounted in a room with controlled-reflectance surfaces designed to test the light output at a 30-inch-high work plane. The team took measurements based on a 1x1-ft grid at the work plane, and reported both

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V_F(V) (Typ.)	9.6V/9.8V/26.5V	38.5V	13.0V	33.0V
Flux(lm) (Typ.)	● 435lm ● 675lm ● 575lm	○ 970lm ○ 1380lm ● 900lm ● 1250lm	○ 1400lm ● 1190lm ● 980lm	○ 9500lm ● 8600lm ● 7300lm
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NEW Federal FM RGB Series		EFERTBW-1CE1	●●●○	1W/3W	R: 620~630	2.1/ 2.3	350/ 700	50/ 100
					T: 520~535	3.3/ 3.7		80/ 125
		EFERTBA-1CE1	●●●●		B: 455~470	3.3/ 3.7		20/ 35
		EFERTTB-1CE1	●●●●		A: 585~595	2.1/ 2.3		50/ 100
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light output and uniformity data.

The conclusions were mixed. Compared with the fluorescents, the SSL products generally delivered about 75% of the foot candles at the work plane. That's a little surprising since in terms of lumen output the fluorescents are generally twice as bright.

The researchers concluded that LED T8s might be suitable for over-lit areas. The report warned that LED replacements could create UL issues since the fluorescent ballast must typically be removed before LED T8s can be installed. But that concern has been addressed within safety-certification bodies, as Intertek detailed in a webcast this year (www.ledsmagazine.com/features/8/3/1).

The good news found in both the Gateway and CALiPER reports focused on high-end troffers rather that the basic fixtures that are broadly installed globally. Still, expect the LED lamp makers to continue to chase the market because of its lucrative potential. ◄

CELMA and ELC publish new documents on LEDs and lighting

Two European lighting organizations, CELMA and ELC, have published two new LED-related documents, which cover standards and safety, as well as a guide on the importance of lighting in general. CELMA and ELC represent the European lighting industry for luminaires and components, and for lamps, respectively. Both CELMA and ELC are supporting organizations for Strategies in Light Europe 2011 (p. 35).

The CELMA-ELC Guide on LED-related Standards (3rd Edition, July 2011) consists primarily of a comprehensive list of relevant standards and publically-available specifications (covering both performance and safety) from international bodies, as well as standards and specifications from the UK, Italy and the USA. It also contains a very helpful list of standards or amendments under development. The ELC-CELMA position paper on Optical Safety of LED Lighting (1st Edition, July 2011) focuses on white-light sources used in households, and evaluates the photo-biological safety of LED lamps and luminaires. A study compared the risk levels of blue-light exposure from LEDs versus conventional lamps, and determined that the "risk levels are very similar and well within the uncritical range."

The CELMA-ELC Guide on the Importance of Lighting (1st Edition, June 2011) explores the benefits of good-quality lighting in general, discussing areas such as improved productivity and health benefits. ◄

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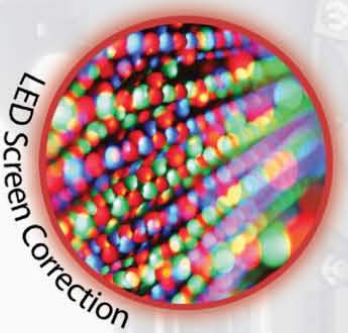

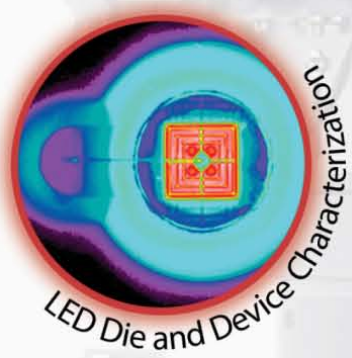

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Street-lighting market shows momentum is behind quality luminaires

A new market-research report from Strategies Unlimited indicates that street-lighting applications are taking off, though the market is currently suffering from a temporary setback.

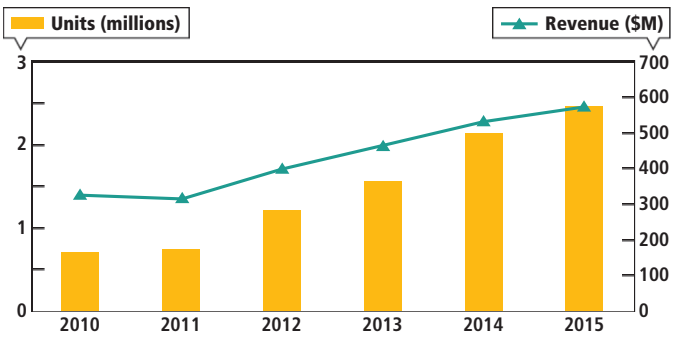
Revenues in the street- and area-lighting market are expected to grow at a compound annual growth rate (CAGR) of 12% between 2010 and 2015, according to a new report entitled "LED Outdoor Area and Street Lighting: Market Analysis and Forecast" (www.ledsmagazine.com/news/8/8/32). *LEDs Magazine* spoke with Vrinda Bhandarkar, the report's author and Director of Research for LED Lighting at Strategies Unlimited (San Jose, CA), a unit of PennWell Corporation, who has been tracking the street- and area-lighting market since 2006. Bhandarkar discussed recent developments and pointed to a temporary market standstill in China due to quality issues, great momentum in Europe and the US, and misconceptions about the role of stimulus packages.

LEDs Magazine: How large is the street- and area-lighting market?

Vrinda Bandarkar: In 2010, it was a $327-million market, which is not huge, but street lights are sort of a gateway technology. When street lights become feasible, the markets for area lights, parking-lot lights, flood lights, wall packs, billboard lights and other lighting applications become available to LEDs.

What markets are included in that number?

That includes worldwide capital spending on street lights and tunnel lights; plus area lights, which includes parking-lot lights, canopy lights, flood lights and wall packs. This is a worldwide estimate of the market size, primarily made up of the US, Europe and China. Markets in other countries at this time are quite small.



Market forecast for LED luminaires in outdoor roadway and area lighting applications. Source: Strategies Unlimited.

What kind of growth do you expect going forward?

We are looking at a CAGR for unit growth of 28% from 2010 to 2015. However, because LED luminaire pricing will continue to depreciate, the revenue growth will be lower, at around 12% (see Chart). The slowdown in China is reflected in a temporary setback for the market in 2011.

What has been the role of stimulus packages, such as the American Recovery and Reinvestment Act of 2009?

The large installations, such as the one that happened in Anchorage, Alaska, and the one that's currently happening in Los Angeles, were not implemented because of stimulus money. They happened because the cities wanted to reduce their operating costs – both the energy used and the maintenance cost of the street lights. These cities did use some stimulus funding, but more funding was provided through grants and financing through other channels such as environmental groups.

But there are so many cities trying LEDs and those are potentially going to result in full-scale installations very soon. I think that was the role of the stimulus – it exposed city officials to this energy-efficient technology. Many people tend to get comfortable with the status quo, but when you are given money and asked to do something with it that will result in energy savings, you take advantage of something like solid-state lighting. Then, when everyone sees the results, there is strong motivation to want to implement LED lighting throughout the city or municipality. I don't think this would have happened otherwise.

And what's going to determine whether these pilot programs go to full-scale implementation, aside from solid performance from the pilot run?

The biggest hurdle for these cities is raising the capital, especially in this difficult economic environment.

Are there other benefits beyond the savings?

Yes, uniformity of light and fewer dark spots. But beyond those qualities, I don't think we can underestimate the value of the political point it makes.

In your press release, you say the US market has taken the lead in proving the viability of LED technology for outdoor lighting applications. Can

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you elaborate?
Yes, the US put an early emphasis on street-lighting quality. Through several programs, such as the Department of Energy's Municipal Solid State Street Lighting Consortium and the DesignLights Consortium, a great deal of effort was made to educate the consumers – meaning the cities – on LED technology, the energy efficiency it can provide, lumen depreciation, and other issues. The DesignLights' qualified-products list alone gives users a good starting point for selecting luminaires.

What about China?
What happened in China was very different. The local governments encouraged the installation of LED-based street lighting and several programs were implemented. However, instead of getting the expected energy savings, there were many cases of premature luminaire failure. As a result, this year China put their street-lighting projects on hold. They realized the need for standards to ensure the quality of every luminaire that is installed.

What will happen next?
Once China implements some standards, and they may borrow from the existing international standards, the market will ramp back up. The top 10-15 suppliers of street lights will begin bidding for projects again, but that may not happen for another year.

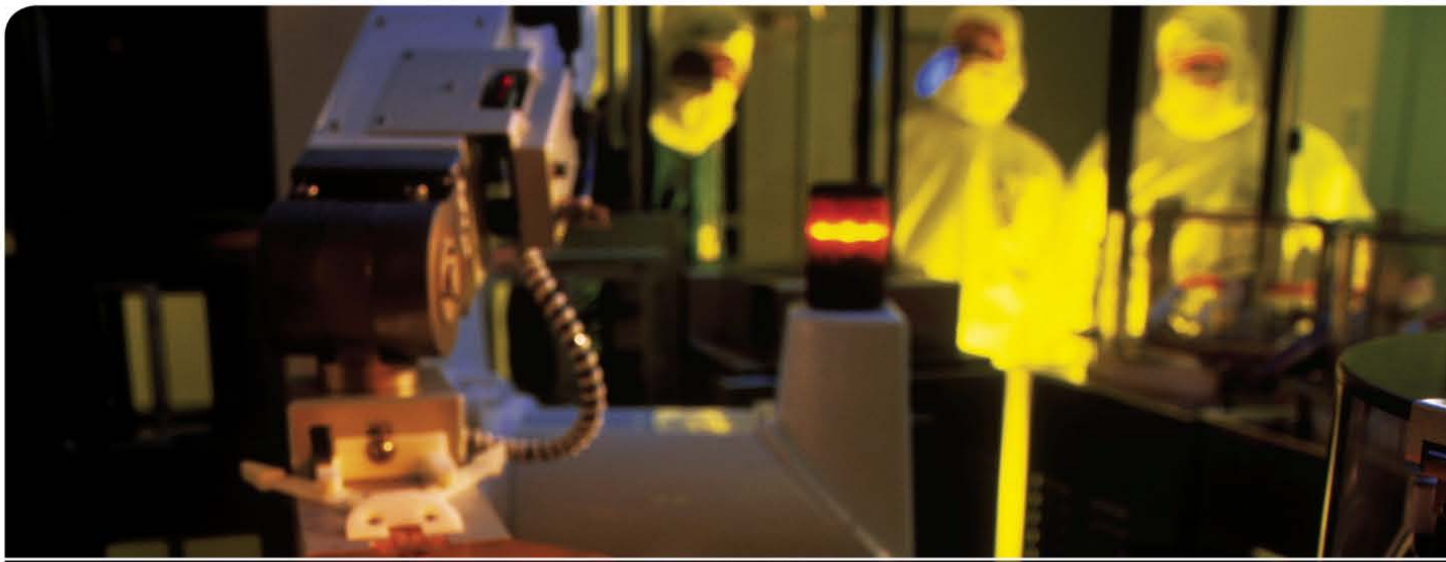
Where do you see the greatest opportunities in this market?
The biggest opportunity exists where old technology is in place – starting with mercury vapor lamps, to fluorescent and incandescent lamps – these are no-brainer applications right now because they pay for themselves in energy savings alone.

Linear fluorescent tubes are common in many parking lots. The fluorescent tubes need to be changed out every year and a half to two years. With exposure to heat, cold and vibration, these fixtures do not perform to their maximum efficiency. They represent another obvious area.

In area lighting, people are also going after high-pressure sodium lights. LEDs offer superior light quality, directionality and the user can reduce lumens and increase uniformity of light, which is the biggest plus for LEDs.

Where do you see maintenance being the biggest factor?
For tunnel lighting, it's critical. When a tunnel needs to be shut down or partially shut down due to luminaire change-outs, the effect on traffic is very disruptive.

What do you see as the next step for lighting-fixture design in this market?
The luminaire designers, especially in Europe, have gotten very creative artistically. When it comes to shop owners and upscale malls, the buyer will be more swayed by the attractiveness of the luminaire and the security the light provides. This is a different value proposition than when luminaires are being sold to a city based mostly on energy efficiency. I think we will see innovative, interesting luminaire designs going forward.



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markets | LIGHTING

Lighting market report predicts strong growth for LED lighting

A recently-released report from McKinsey & Company on the worldwide lighting industry indicates sizable growth for LED-based lighting, says **LAURA PETERS**.

The worldwide lighting market will grow to approximately EUR 110 billion ($159 billion) in 2020, with 80% of that total from general lighting, according to a report from McKinsey & Company (Munich, Germany).

McKinsey was commissioned by Osram, Siemens' lighting division, to examine the worldwide lighting market and to investigate the adoption patterns of SSL through the year 2020. The McKinsey report can be downloaded from the *LEDs Magazine* website (www.ledsmagazine.com/news/8/8/5).

The report tracks general lighting, automotive lighting and backlighting as the three largest lighting-market sectors at present, with general lighting (broken down into numerous segments, of which residential is the largest) accounting for about 75% of the total market in 2010. However, the report does not include other lighting applications within this sector, such as signal, signage or medical lighting, which together account for a total market share of under 10%. In addition, the market impact of organic LEDs (OLEDs) on general lighting were not included due to poor visibility into OLED adoption rates.

The global LED lighting market is expected to grow from EUR 7 billion in 2010 to EUR 40 billion in 2016 – a compound annual growth rate (CAGR) of 34%. Subsequently, growth is expected to slow down, with a CAGR of 13% from 2016 to 2020. The LED lighting market will amount to almost EUR 65 billion ($94 billion) by 2020, representing close to 60% of the total lighting market.

The report says that "the significant differences in LED technology versus other lighting technologies will lead to a fundamental disruption of the lighting industry along the entire value chain." Standard lighting approaches are being challenged by entirely new possibilities enabled by LEDs, such as design flexibility, or the ability to dynamically change the color temperature of light. The controllability of LED-generated light enables intelligent lighting systems, and McKinsey estimates that the revenue from control-system components will reach EUR 7 billion in 2020.

While the rate of LED penetration in residential lighting is slower than in other general-lighting segments, the residential LED lighting market is likely to be worth over EUR 20 billion by 2020. Architectural lighting has been an early adopter of LED lighting due to benefits such as color control, and is expected to see 85% LED penetration by 2020. Rapid growth in LED penetration is also expected in hospitality-, shop- and outdoor-lighting applications. However, the proliferation of cost-competitive linear-fluorescent lamps in office and industrial lighting will mean that penetration of LEDs will be slower in these applications.

	Residential N = 338	Office N = 399	Industrial N = 261	Shop N = 259	Hospitality N = 127	Outdoor N = 232	Architectural N = 235
Lifetime of light source	9	12	16	8	14	12	9
Purchasing price of light source	22	11	17	10	9	14	9
Fixture design affected by light source	10	10	8	19	14	5	20
Shape of light source	10	7	5	6	6	11	7
Light quality	20	30	23	30	25	21	26
Light controllability	8	9	8	7	16	6	12
Life cycle cost/ energy efficiency	14	14	17	15	13	21	12
Easy installation	8	8	5	5	2	10	5
Other	0	0	1	0	0	0	0
Total	100%	100%	100%	100%	100%	100%	100%

Lighting professionals and consumers selected the most important design criteria when deciding on the type of light-source technology for fixture installations in new building/structures. Light quality was the most important concern for all applications except residential, where purchase price came top. Numbers show percentage of responses. N = number of respondents for each application. Source: McKinsey.

Why people buy LED fixtures

In June 2011, McKinsey conducted a global survey of 650 lighting professionals and 1000 consumers to estimate LED market share of lighting fixtures by application, including office, shop, hospitality, residential, industrial, outdoor, and architectural lighting. The lighting professionals included lighting designers, architects and electrical engineers, and participants were from the USA, Germany, Japan, China, Russia, Brazil and India.

The buyers indicated their number-one

LAURA PETERS *is a Senior Technical Editor with LEDs Magazine.*

purchasing criterion when selecting new lighting fixtures in up to three applications (see chart). Quality of light, which includes CRI, color temperature, color consistency and light distribution, ranked the highest for all applications except residential, where it was outranked by purchase price. The second-highest concern was lifecycle cost/energy efficiency for all applications except residential.

In the survey, lighting professionals and consumers were also asked to identify a payback period (in years) that would encourage them to choose LED over traditional lighting, by application. The results showed that most people required payback of three years or less. The acceptable payback period for residential lighting had the highest proportion of participants (22%) that expected payback in less than one year.

The acceptable premium that people were willing to pay for a new lighting fixture for the first installation varied on average between 30% above cost (for residential) and 39% (for office lighting). However, the median value was at 20% for all applications except for office lighting, which had a median value of 30%.

General lighting

A key finding of the report is that growth of the general lighting market is highly correlated with local construction investment, so it is no surprise to see that Asia, and China in particular will experience the most-rapid growth. Asia already accounts for around 35% of the general-lighting market, and this figure is set to rise to around 45% by 2020. Europe and North America will follow, with market shares of 25% and 20% respectively.

The report describes the general-lighting market as fragmented, due to the fact that lighting is used in so many different applications, with many types of light sources and many different parties responsible for purchasing decisions. The local landscape of fixture manufacturers depends on the region: there are over 100 fixture companies in Europe, but in the US the fixture market is relatively consolidated with four large companies. In Japan, the top two companies have a large market share, while China has many local companies including OEM suppliers for overseas brands.

The report predicts that the lighting-fixture market will remain fragmented because of the local buying power of governments, construction firms, architects and designers. This is in contrast with globally-consolidated electronics manufacturers.

In Asia, North America and Europe, the current LED share of the general-lighting market is similar, at around 7%, but in each case this is expected to grow to around 70% by 2020. LED penetration will be slightly higher in Europe and North America than in Asia.

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Strategies in Light Europe

Strategies in Light Europe addresses LED lighting market challenges

With a theme of "Enhancing the Quality and Performance of LED Lighting," this year's Strategies in Light Europe 2011 conference takes place in Milan, Italy on October 4-6.

After a successful launch in September 2010, the Strategies in Light Europe conference and exhibition moves to Milan, Italy. The conference program addresses key issues surrounding the evolution and transformation of the lighting market, and the ongoing development of higher-quality, higher-performance LED lighting.

Tim Whitaker, Conference Director and Editor-in-Chief of *LEDs Magazine*, said: "We believe we have assembled a conference program that provides an excellent and comprehensive update on the current status of the LED lighting industry, and that will offer valuable insights into future directions and strategies for business success."

The Keynote session on Tuesday will set the scene for the conference, with talks from McKinsey and Strategies Unlimited that will discuss the global LED lighting marketplace, identifying trends and opportunities for solid-state lighting. Both organizations are likely to discuss aspects of their respective reports – for details, see pages 28 and 31 of this issue. Also in the Keynote session, Simon Fisher of GE Lighting will discuss how LEDs can provide an opportunity to redefine the rules for designing the lit environment.

Europe is obviously a major focus of the conference, and in Wednesday's Plenary session Paolo Bertoldi of the European Commission will provide a status update on LED lighting in the European Union. Other sessions on European initiatives will discuss the EU LED quality charter, and the possible need for an LED performance label, as well as the European program on metrology.

Also in the Plenary session, Philips Lighting will discuss the next phase in LED illumination, which will be associated with rigorous cost reduction. Osram Opto Semiconductors will look at the status and potential of organic LED (OLED) technology and products, discussing whether OLEDs are ready to take off in general-lighting applications. And Marc Fontoynont will report progress from the global IEA Annex on SSL, which is aiming to build consensus on quality and metrology issues.

From mid-morning on Wednesday, the conference splits into parallel tracks, which are focused on Market Transformation and Technology. The latter track will include talks ranging from the use of wireless DALI as a control technology for LED luminaires, to the development of optical systems using reflectors, light-guides and lenses, to the capabilities of materials such as silicones and thermoplastics. A session will discuss retrofit lamps, clearly a major issue following the phase-out of low-efficiency 60W lamps in Europe from September 1, 2011.

In the Market Transformation track, a session on standards contains a talk by CELMA, one of the event's Supporting Organizations, discussing the importance of standardization of performance requirements for LED luminaires. Another talk will describe the CIE's work related to LEDs and lighting.

Recent additions to the program include a talk from Philips Lumileds on the performance requirements for LEDs in general-lighting applications, and a presentation from ELC (another Supporting Organization) explaining the activities of the Global Lighting Forum.

All this, and much more. The organizers of Strategies in Light Europe – LEDs Magazine, Strategies Unlimited and PennWell – look forward to welcoming you to Milan.

MORE: www.sileurope.com

Conference Program – see www.sileurope.com for details

Tues 4 Oct, 09:00-12:00	**Workshop A** – Thermal Management	
Tues 4 Oct, 10:00-15:00	**SSL Investors Forum**	
Tues 4 Oct, 12:30-15:00	**Workshop B** – Light Measurement for SSL	
Tues 4 Oct, 15:30-17:00	**KEYNOTE Session** – Main Conference	
Wed 5 Oct, 08:30-10:30	**PLENARY Session** – Main Conference	
Parallel Tracks	**Market Transformation**	**Technology**
Wed 5 Oct, 11:00-12:00	European Initiatives #1	Luminaire/System Design
Wed 5 Oct, 13:30-15:00	European Initiatives #2	Drivers & Dimming
Wed 5 Oct, 15:30-17:00	Standards	Networks & Control
Thurs 6 Oct, 08:30-10:00	Market Development	Retrofits Lamps
Thurs 6 Oct, 10:30-12:00	Lighting Applications #1	Optical Materials & Packaging
Thurs 6 Oct, 13:00-15:00	Lighting Applications #2	Optics

conference | **DOE WORKSHOP**

DOE workshop discusses LED success stories, labeling programs and quality issues

Presenters at the DOE SSL Market Introduction Workshop looked at the SSL success stories, analyzed different cost-reduction strategies and ways of reporting luminaire reliability, and examined the implications of the FTC Lighting Facts label. **LAURA PETERS** reports from Seattle.

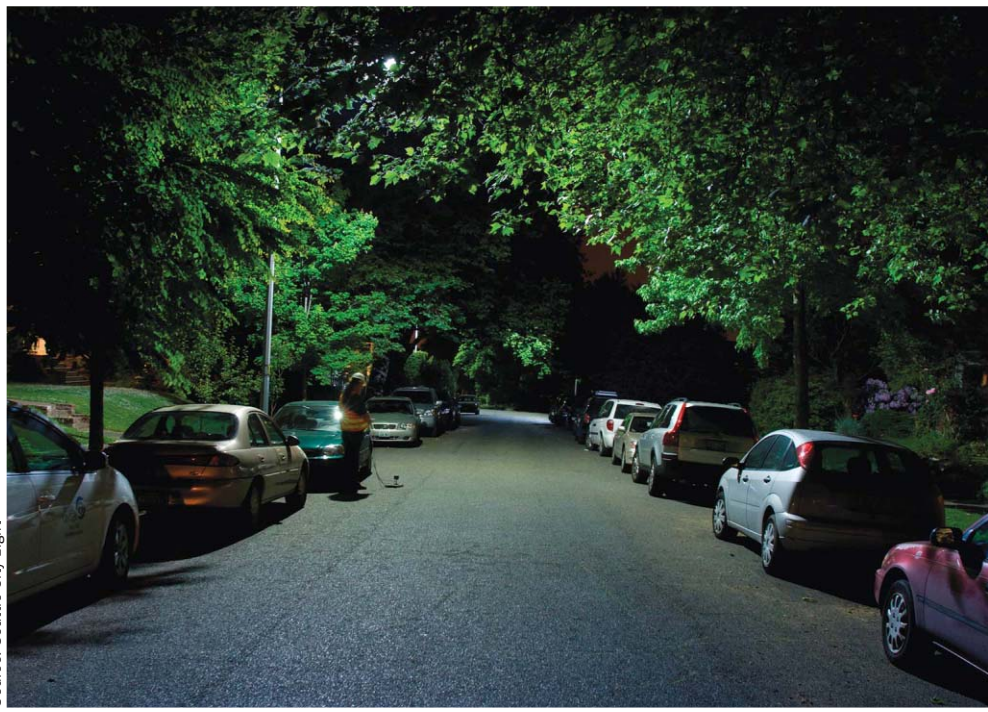
The annual US Department of Energy (DOE) SSL Market Introduction Workshop took place in Seattle, Washington on July 12-14 and was attended by 275 industry professionals including lighting designers, lighting manufacturers, LED and driver manufacturers, utility companies, and energy-efficiency companies. Highlights of the workshop included several real-world success stories, a discussion of the new FTC Lighting Facts label and how it differs from the DOE Lighting Facts label, a new report on reliability, and ways of bringing down SSL costs throughout the supply chain.

Jim Brodrick, who runs the DOE's SSL program, stated in one of his weekly Postings emails that the Workshop indicated just how far the SSL industry has come over the past year. He said that "while SSL is not yet suitable for every application, it's become a definite force to be reckoned with." The industry is clearly getting some of the help it needs – from government incentives to utility rebates to technical developments – to succeed in the replacement of incumbent, less-energy-efficient lighting options.

The maturing of the LED lighting industry can be seen in the increasing number of large-scale installations across the country. At the Workshop, the principal installers discussed the lessons learned from installing LEDs in two art galleries, the city streets of Seattle and US Navy parking lots.

Streets of Seattle

The home of the DOE workshop this year also happens to be a showplace for LED street lighting. At the workshop, Bruce Harrell, Council Member of the Seattle City Council, discussed the successful installation of over 6000 street lights by the publicly-owned utility Seattle City Light (see Fig. 1). The project is part of the plan to replace 41,000 residential street lights in Seattle by the end of 2014, a program that is already saving the city $300,000 per year (www.ledsmagazine.com/news/8/7/11). Once completed, the city council estimates a $2.4 million reduction in operating costs will be achieved.



Source: Seattle City Light

FIG. 1. A Seattle side street is well lit with LED-based lamps, eliminating the "hot spots" or gaps in lighting often seen with HPS street lights.

Edward Smalley, council member of Seattle City Light, said the decision to install LED-based street lighting was the result of LED's demonstration of the illumination performance, controllability and operational efficiency (48% energy savings) needed to satisfy the city's lighting needs.

Council members were also swayed by the tremendous savings in maintenance costs. "Every two years, we would pay workers overtime to quickly replace the high-pressure sodium lamps before the winter came," Smalley said. "Now that cost has been essentially eliminated."

Smalley said that feedback from local law enforcement indicates the LED street lights

LAURA PETERS *is a Senior Technical Editor with LEDs Magazine.*

make criminal activity easier to identify. He said this is due both to the better quality of the LED light and the elimination of "hot spots," which are prevalent with HPS street lights.

Smalley is the director of the DOE Municipal Solid-State Street Lighting Consortium (http://www1.eere.energy.gov/buildings/ssl/consortium.html), which has more than 270 members. Consortium membership is free and open to cities, utilities and investors involved in street- and area-lighting projects. The consortium builds a repository of shared field data to help accelerate the learning curve for LED street lighting.

Lighting in art galleries

Lighting designer Scott Rosenfeld had no complaints about the light quality in the Smithsonian American Art Museum and the Renwick Gallery, both in Washington, DC, but he wanted a more energy-efficient alternative. Rosenfeld, chair of the IES Museum Lighting Committee, explained the unique challenges associated with illuminating art. "Any light causes damage, so we use the smallest quantity of light necessary to experience what is relevant about the object," he said.

Rosenfeld turned to LED lighting after evaluating fluorescent and metal-halide lighting technologies and determining that they could not match the performance of the existing halogen products in the galleries. Fluorescent, in particular, would cause additional damage to artwork due to the ultraviolet light component.

Effective illumination of artwork involves precise control the lighting intensity, angle and distribution. Rosenfeld chose a mixture of LED wall-washing and spotlighting lamps, including replacements for PAR30, PAR38 and MR16 lamps, with beam angles from 4 to 54 degrees. Some lights had to remain incandescent, because there was no suitable LED alternative, for instance, for 250W incandescent spot and flood lamps used with the high ceilings (34 ft) of the Renwick Gallery.

Rosenfeld commented that the early part of the LED installation was dominated with flicker issues, especially with MR16 lamps. The museum overcame these issues by using magnetic ballasts.

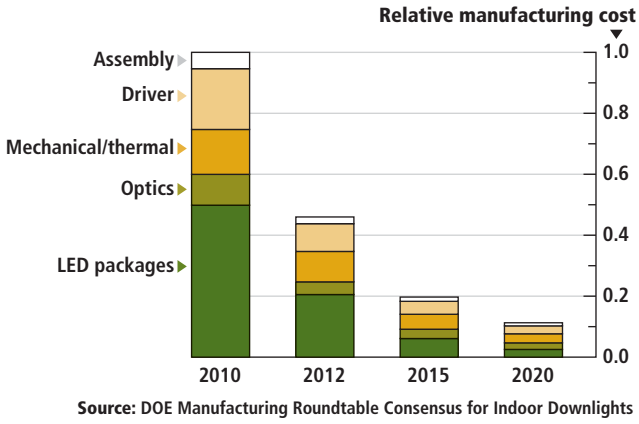
The switch to LEDs in the two galleries is expected to reduce lighting power density in the Renwick Gallery from 3.9 W/ft^2 to 1 W/ft^2, and in the Smithsonian American Art Museum from 2.9 W/ft^2 to 0.5 W/ft^2. Overall energy consumption in the two galleries is expected to decrease by 75%.

As part of this Gateway study, the DOE surveyed members of the viewing public to determine their preference for the quality of light among three LED flood-lamp options and a halogen lamp (see Table). One LED lamp scored particularly highly (lamp 2), though the halogen lamp also scored highly. This survey confirms what Rosenfeld has observed with the LED replacements: viewers discern little difference, if any, between a high-quality LED replacement and halogen lighting.

Viewing public's assessment of four light sources

	LED Lamp 1	LED Lamp 2	LED Lamp 3	Halogen
Overall light distribution on art	0	23	8	23
Ideal warmness/coolness of light	10	37	12	8
Best lamp for oil painting	6	25	15	15
Best lamp for black-and-white photo	1	29	14	4

Source: DOE pre-analysis, Gateway demonstration program



Source: DOE Manufacturing Roundtable Consensus for Indoor Downlights

FIG 2. Future cost targets for LED luminaires.

US Navy

Paul Kistler of the US Navy (Seattle, WA) shared his experience with changing out parking-lot lights from HPS lights to LED luminaires on naval bases in Ventura, CA and the naval station at Pearl Harbor, HI. In Ventura, the Navy replaced 14 400W HPS luminaires with 207W LED luminaires, achieving a 21% improvement in minimum illumina[tion] [and] $1412 per year energy sa[vings].

At Pear[l Harbor] changed out 34 150W HPS luminaires for 104W LED luminaires, improving minimum illumination by 225% while still reducing the energy cost by $1280 per year. "We are mandated by Congress to reduce our energy use by five percent per year, and at the same time these lighting projects have become showpieces for the Navy," explained Kistler.

Kistler added that the installations provide better lighting quality and security, and the Navy expects to improve the energy savings further through increased use of sensors and intelligent controls. With such projects, the US Navy looks for utility incentives, 5-year warrantees on the products they purchase, and luminaires with corrosion resistance, efficient thermal management and good ventilation.

He also promoted the value of checking LM-79 and LM-80 data for any products that are under serious consideration, checking DOE Caliper data for the class of products considered, and assessing whether lighting products can dissipate heat well.

Meeting aggressive cost targets

The industry has set very aggressive cost targets, including a 50% reduction in luminaire cost from 2010 to 2012 and greater reduction between 2012 and 2015 (see Fig. 2). As Fred Welsh, President of Radcliffe Advisors (Chestertown, MD) explained, luminaire manufacturers are moving toward a more integrated model, using fewer components to reduce assembly and testing costs.

A breakdown of packaging and material costs (see Fig. 3) indicates that cost reduc-

tion in several areas is needed. For high-volume luminaire production, new equipment is needed to maximize yield and consistency of manufacturing results. Welsh said that increased equipment throughput is needed with increased automation for MOCVD, improved testing and inspection techniques, and improved upstream process control. From the LED packaging side, simplified designs are required and the industry should move to wafer-scale packaging technologies.

Mike Watson, Senior Director of Marketing at Cree (Durham, NC), called for more radical change throughout the manufacturing supply chain. He suggested building a new ecosystem and new business models for the SSL market. In this ecosystem, financial-service companies should monetize the energy savings for the consumer. This can be provided through lighting and energy-control companies, lighting-systems integrators and leasing experts.

Mark Hand, Director of New Products and Technology at Acuity Brands (Atlanta, GA), talked about the need for more realistic specifications to reduce cost. For instance, specifications of 50,000-60,000 hours may be reasonable for applications that run 24 hours a day, 7 days a week, but he said that 10,000-20,000 hours may be reasonable for a majority (80%) of applications. This could allow the LEDs to be run hotter, either yielding a higher light output or reducing the cost of the thermal-management components.

Hand also advocated delivering only the CRI that is necessary for the application, and suggested that customers specify only the necessary level of restrictions on binning to reduce cost.

Quality of light

A recurring theme in several workshop presentations was the need to assess the quality of light from SSL. Maria Thompson, Principle Applications Scientist at Osram Sylvania (Danvers, MA), said that the industry is making rapid progress in performance, having already broken the 200 lm/W efficacy barrier that was set as a target for 2020. However, the potential for delivering improved color quality is essentially untapped.

Thompson described the limitations of CRI. "CRI, which is a color fidelity metric, reflects the ability to reproduce colors as close as possible to those perceived under sunlight, or blackbody radiation," she said. "However, CRI is based on eight unsaturated colors, and it not only doesn't account for color saturation, but it actually penalizes for color saturation."

Thompson explained that color distortions with increased chromatic contrast (increased color saturation) are typically preferred by viewers. The Color Quality Scale (CQS) developed by the National Institute for Standards and Technology (NIST, Gaithersburg, MD), does take into account color saturation, though it also is an average

value, like CRI. Given the limitations of both CRI and CQS, Thompson suggested further investigation into improved metrics for general lighting applications for SSL white light.

Chad Stalker, Regional Marketing Manager of Philips Lumileds (San Jose, CA) took a slightly different approach to defining the quality of light, and discussed the different color-rendering needs in terms of application. He compared food displays, which require excellent color rendering, versus street lighting, which requires lower CRI. He explained that LEDs require color consistency in five areas:

- Color spectrum and rendering: Measured by CCT, CRI, R9, CQS
- Color consistency between sources: <3 SDCM (standard deviation of color matching)
- Color in application: Measured at 85 degrees junction temperature
- Color consistency in beam: <10 points on u'v' scale

- Color consistency over lifetime: <5 SDCM

Stalker advocated testing and binning LEDs at their operating conditions to reduce costs, simplify the design process and raise purchasing confidence.

Practical color variations

Daniel Salinas, a lighting-systems designer with Nelson Electric (Seattle, WA) provided feedback from the perspective of a designer and installer of lighting fixtures. He said that color variance for an overall project can be minimized by purchases products from a small number of luminaire manufacturers. To simplify installation and maintenance, he also suggested minimizing the number of control technologies and drivers used on a project. "I recommend that the designer and the customer establish an acceptable level of color variance or color shift, make that a part of the binning requirements, and include it in the contract agreement upfront," he said.

Salinas also suggested that lighting samples be made available during the design process and that these be tested together with the materials of the room (wood, carpet, artwork, etc.) to ensure customer satisfaction.

Salinas defined project life as typically 5-7 years, and said that during that time, the light fixtures will need to be cleaned and maintenance will typically be needed on drivers, so accessibility to both is important. He added that adequate ventilation for LEDs is critical. Finally, he said that luminaires should be checked for UL listing before the project begins.

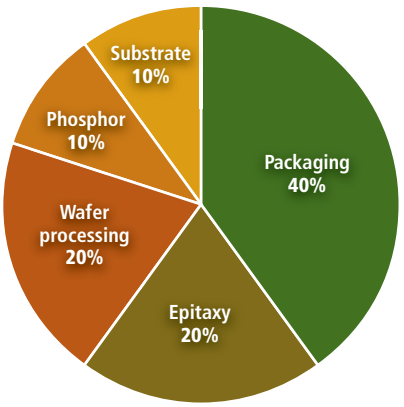
Update on Lighting Facts labeling

Effective January 1, 2012, the US Federal Trade Commission (FTC) will require that manufacturers of medium screw-base bulbs (table-lamp-size bulbs), whether incandescent, fluorescent or LED-based, include the new FTC Lighting Facts labels on the front and back of the bulb's packaging. Also, the bulb itself must contain the light output (in lumens) and the fact that it contains mercury (if it does).

The US FTC mandates that these labels (see Fig. 4) appear on products sold on and after January 1, 2012. The front label contains light output (lm) and energy cost ($/yr), while the back FTC Lighting Facts label contains light output, energy cost, lifetime estimate (years), appearance (CCT), required power (W) and presence of mercury.

Until very recently, the lighting industry has used the voluntary DOE Lighting Facts label. The DOE has stated that its label is not in conflict with the new FTC Lighting Facts label, and will still be used by lighting professionals, utilities and retail buyers. The FTC label strictly targets consumers. However, the DOE will no longer use its label on medium screw-base products after January 1.

A notable difference, however, is that the DOE Lighting Facts label program has attempted to control the label's content by encouraging third-party testing and verification at certified laboratories. Though this action was voluntary, Lighting Facts partners had a greater tendency to publish data that was independently verified with LM-79 test data than non-partners.



Source: Estimated by DOE Cost Modeling Working Group

FIG. 3. Cost breakdown for packaged LEDs in 2010: higher-throughput MOCVD (epi) processes, larger wafer substrates and wafer-level packaging would all help reduce costs.

Now, the FTC labeling is required. Unlike the DOE, the FTC in principle has the power to ensure that manufacturers only publish accurate metrics on the label. Only time will tell whether the FTC will take action against manufacturers that publish false performance metrics.

Luminaire reliability

The SSL Quality Advocates, a working group formed jointly by the US DOE and the Next Generation Lighting Industry Alliance (NGLIA), announced a new report at the workshop entitled "LED Luminaire Lifetime:

Recommendations for Testing and Reporting."

Members of the working group included Fred Welsh, Terry Clarke, CEO of Finelite, and Steve Paolini of Lunera Lighting Inc. Welsh pointed out that many people in the industry still ascribe lumen depreciation to luminaire lifetime. In a simple example, he explained that lumen depreciation of an LED might lead to lifetime estimates of 60,000 hours, but when driver lifetime (55,000 hours) is taken into account (failure probabilities are multiplied), the lifetime of the system will be more like 52,000 hours.

The working group recommends defining the standard luminaire lifetime as the time when half the product population falls below 70% of initial light output for any reason. Additional specifications might be provided for color shift, such as an amount of color shift after a measured period of time.

Clarke emphasized that color shift in LEDs is significant, complex and not well understood. He added that not all color shift comes from the LED itself: different luminaire designs impact color; different optics and designs can age differently; different environmental operating conditions may cause color shift; and the luminaire may or may not use active color management. Though the working group could not come to an agreement on ways to characterize color shift as a metric of reliability, they consider it a significant factor in luminaire performance.

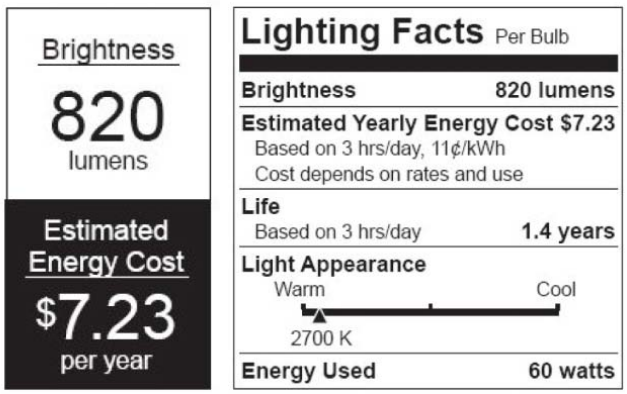


FIG. 4. FTC lamp labels.

Paolini talked about the value of temperature cycling and highly-accelerated life testing – designed to identify the weakest component in the luminaire – to enable design improvements. "These tests can help you improve the design, but only long-term reliability testing at normal use conditions will give you an indication of how long the luminaire will last." For more on the recommendations, see www.ledsmagazine.com/news/8/7/13.

business | INNOVATION

Getting the innovation right: the need for evaluation, measurement & validation of LED lighting

Success in the solid-state lighting market requires a system-engineering approach that demonstrates real value to customers, where results can be validated by real-world testing, as **MARTHA CARNEY** and **JIM FAY** explain.

Bringing products to market based on new technology is a risky business. The small number of truly successful innovations contrasts with the large number of new products that have failed to realize their promise. It can be confusing to read about how advancements in LED technology are transforming the lighting industry, because that future won't happen unless we get the innovation right. We should consider how solid-state lighting (SSL) technology companies can employ system engineering, with all critical stakeholders using better measurement, validation and communication to get the innovation right in today's new economy.

To efficiently penetrate the market and realize its full potential, key stakeholders must play their part in building a comprehensive and accurate body of knowledge about the new product experience. This will assist the earliest customers in making informed, thoughtful and prudent decisions, and help build the market on a foundation of realized expectations.

Such a body of knowledge includes two important components. First is the technical performance of the product in real-world conditions. This includes all aspects of the whole-product performance (including the LED chips and their drivers), and encompasses energy savings and power quality; product life and maintenance; light output, color, temperature, and uniformity; dimmability and controls performance; and environmental impacts.

Second is the user benefits and real-world impact of the product. In the case of SSL, some possible impacts include:

- The relative value of an entirely-new customer experience. This can only be understood through gauging consumer reaction to the in-situ experience of an activity under the new lighting conditions.
- The enhanced brand of a retail business and its attractiveness to customers, as well as enhanced real-estate value.
- Monetizing the value of improved productivity and health of employees, or of livestock in agricultural environments.
- Increased safety and security of business and municipal environments.

LED lighting represents perhaps a true opportunity for a potential technology home-run. In the March 2011 issue of *LEDs Magazine*, Philip Keebler of the Electric Power Research Institute (EPRI) demanded "show me the data" and pointed out the need for more measurement and validation of system efficacy, driver efficiency, and power quality. We agree, and call for even further data analysis that is focused on the customer.

Today's customers increasingly rely on the internet, social media and customer testimonials to learn about new products. Word of the initial product experiences of early adopters are likely to spread quicker and further, and therefore are more influential in driving future market decisions. If product performance claims are not backed up with solid field data, mainstream adopters will be more skeptical, affecting market share. Those LED manufacturers that listen to customers and deliver and report authentic new value will be the successful ones.

Manufacturers as stakeholders

The market for new lighting products is competitive, and the potential rewards are high. Manufacturers must trade off the desire to be first to market with the need to provide the market with robust information about product capabilities and performance. Successful products will be focused on meeting stated and unstated customer needs. New-product-development guru Robert Cooper (www.prod-dev.com) says the inability to effectively match a new product to real-world customer needs is the most frequent reason for new product failures in America.

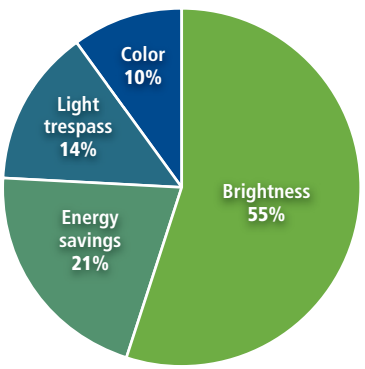


FIG. 1. Residents in Apple Valley, MN, rated the level of importance of various characteristics of an outdoor residential-area lighting system.

MARTHA CARNEY *and* JIM FAY *are with Outsourced Innovation, a solid-state lighting consulting firm based in Naperville, Illinois (www.outsourced-innovation.com).*

Getting truthful answers to the good, bad and sometimes painful side of LED lighting is critical to ultimate market success. Among the key questions are:

- What drives a consumer to pay (or not pay) for energy efficiency?
- What level of dimming provides energy savings without sacrificing perceptions of safety in outdoor lighting?
- What are the primary components of value, and what are they worth?
- Alternatively, what are the pain points with today's lighting that will drive consumers to LEDs?

For companies intending to be in the market for the long haul, it makes good business sense to be a leader by providing decision makers with a robust body of knowledge regarding new products. Measurement and validation should include:

- Relevant customer research data
- Test data for standards and certification compliance
- Independently-verified field-performance data
- Case studies to illustrate the application and customer reaction.

Demonstrations

Outsourced Innovation has managed over 15 LED demonstrations in collaboration with Midwest utilities, ranging from outdoor street and area lighting, to on-campus university lighting, to creating LED lighting conversions in agricultural settings. Among the lessons learned from these demonstrations is that measurement and validation clarifies product performance and aligns expectations with proven performance. Also, business value beyond energy savings is just as important and needs to be evaluated, too.

A true breakthrough will not occur just because LED technology is used, but because of the added value the technology brings to enrich our lives. We need to understand and monetize that added value.

The DOE works hard to publish realistic reports from both Gateway and Caliper programs. These studies help temper the "coolness" factor surrounding the notion of digital lighting, so the marketplace won't be disappointed with LEDs.

If there is an unforeseen problem or disappointment with SSL, the product can leave a bad impression with the public. Even if a fix is found that makes the product superior to anything else in the marketplace, the damage can be irreversible and be further exacerbated with today's social-media tools. So understanding your customer and the complex operation of SSL systems is advisable before making one big enthusiastic sales pitch on LEDs.

FIG. 2. An LED conversion program at the convention center in Bettendorf, IA.

Municipal and commercial customers

The City of Apple Valley, MN, and its host utility Dakota Electric Association surveyed residents as part of a recent demonstration project. Brightness was found to be the most important characteristic in a residential street-lighting system. Surprisingly, energy savings, light trespass and color were far less important to consumers (Fig. 1). These results suggest that, when residents view brightness as far more important than energy savings, education is needed to support the rationale for reducing light levels during after-midnight hours.

The good news is that our research consistently shows that, no matter what the geographic location, LED outdoor lighting is preferred to conventional street lighting by a factor greater than 7. But a related question for builders and home buyers is this: will an LED lighting system create a more attractive place to live, adding new value to real estate? New product research should characterize that value, as it will help justify a scalable deployment of new and more expensive technology.

Another promising example includes the city of Bettendorf, Iowa, which is collaborating with its host utility, MidAmercian Energy, to better understand the performance of LED lighting in front of the downtown Quad Cities Waterfront Convention Center (Fig. 2).

After testing several manufacturer's products, the city chose thirty-two Capella LED fixtures from Philips. The lamps were installed on State Street and promise to deliver a 45% energy saving. The city of Bettendorf routinely tracks residents' perception of downtown safety at night (Fig. 3). Results show a 20% increase in the city's safety score at night following the installation of LED streetlights in 2009. Defining additional value of this type will be important in order to accelerate the technology adoption with other municipalities.

Taking it one step further, the city of Bettendorf could track whether the downtown convention center attracts more visitors or lures more booked conventions due to the installation of SSL systems. Again, this level of evaluation could help to justify such installations.

Business tactics such as these are referred to as Blue Ocean strategies, where value innovation becomes so important that competition is irrelevant and price becomes inconsequential. This is a good market strategy for SSL as long as we understand it and leverage the technology to create meaningful value that goes well beyond energy savings.

There is a growing body of evidence that customers are installing LED lighting products like light bulbs, with very little if any efforts to understand the nuances of the semiconductor technology or consideration of whether it indeed makes a good business case. But doing business without listening to the customer is like sailing a ship without a rudder: it may take a lot longer, or worse yet we may never get there.

Lighting professionals may not always understand the unique photometric characteristics of LEDs, or their optical or thermal

behavior. They may not have regard for what type of LED lighting system the community prefers on the parkway in front of their homes, or whether residents may want to have less-bright streetlights or even the ability to control brightness. New innovation cannot survive on intuition alone.

These communities can be our labs. A close watch of customer insights can bring innovation to the most iconic and established products like lighting. But a lack of coordination and good data collaboration has been a big barrier to innovation in the past.

Swine – Farrowing Facility: 26-watt CFLs to 15-watt LED

	Average Illuminance		MAX		MIN		Max/Min		Coefficient of Variation		Uniformity	
	CFL	LED	CFL	LED	CFL	LED	CFL	LED	CFL	LED	CFL	LED
Photopic	5.2	5.0	8.5	18.7*	1.3	0.8	6.5	23.4	.28	.70	4.0	6.3
Scotopic	6.6	7.3*	11.9	27.9*	1.7	0.7	7.0	39.9	.29	.74	3.9	10.4

* Denotes matched or better performance

TABLE 1. Photometry comparison of CFL versus LED in a swine facility. Data represents 89 measurements on 3x5-foot grid.

Examples from agriculture

Another critical example involves US-based agricultural businesses. What problems have evolved in such operations using today's energy-efficient lighting systems, and what new value can be engineered into an LED system?

The National Rural Electricity Cooperative Association's (NRECA) Cooperative Research Network, along with Oklahoma State University, has commissioned several agricultural LED field assessments to seek some answers. Early power-quality measurements suggest LED performance that is true to manufacturers' claims, and that has matched or slightly better light levels (Table 1 and Table 2) compared with incumbent technologies. Energy savings of 50% have been validated for LED conversions in both swine and dairy facilities.

These results are laudable, especially as the measured LED lights at both agricultural test sites put out the same amount of illumination as the legacy lighting systems they've replaced.

For these field studies, researchers hope to prove that the added value goes beyond

energy savings. The hypothesis is that animal livestock and poultry will exhibit measureable weight gain or increased milk production, or that farmers could realize a reduction in feed costs by leveraging the spectral light intensity of LEDs. Many of today's progressive farmers have advanced tracking systems in place to evaluate behavioral data, along with the power-usage data collected by the utility, so the full value of the new lighting system can be determined.

Rich Robinson of Robinson Family Farms, who owns and manages a swine operation with 22,000 sows in Holdenville, OK, reported: "As you can imagine, our operation is harsh and dirty. The energy saving from the LED prototype lamps in our swine facility is proven, but now we can hose and foam-clean the lamps without fear of breakage, which is a common occurrence with CFLs."

Robinson further commented: "We've gone through 3 cycles of piglets with no damage or breakage to the LED lights and that's substantial when we typically replace many CFLs each month. That's the real value of LEDs for our operations."

Table 2 shows promising results from an LED dairy conversion project for about 120 milk-producing cows. However, these findings beg the question: will more LED fixtures be required or could re-engineered optics provide the additional benefit of driving a behavioral change? And especially as past research implies that 15 foot-candles are necessary to instigate an increase in milk production (Josefsson et al., 2000). The answer appears to be no, more LED fixtures may not be required: early field data at the dairy is showing a 13% increase in milk yield on the LED side of the barn, suggesting a compelling argument for LEDs. However, there is a need for continued study.

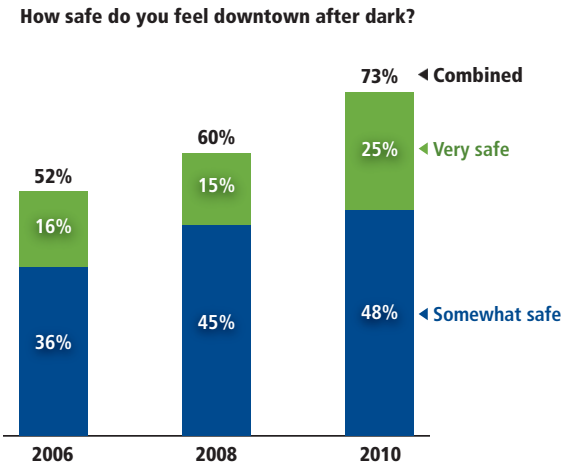


FIG. 3. Residents' perception of safety in the city of Bettendorf, IA, increased following the LED installation in 2009 (+5% margin of error).

Utilities as stakeholders

Electric utilities have an important role in demonstrating significant new energy-saving products and in facilitating their adoption in applications that make good business sense. CFLs have been a pillar of utility energy-efficiency program portfolios, but now utilities are beginning to embrace SSL.

Utilities and their regulators are recognizing the importance of a comprehensive measurement and verification approach to validate the full value of SSL and ensure an apples-to-apples baseline comparison for determining energy-efficiency savings.

Outsourced Innovation recently held a workshop for MidAmerican Energy on solid-state street lighting, bringing together Iowa municipalities, manufacturers and distributors. The main take-away from the workshop was how utilities and municipalities typically don't have the staff to select a quality LED system. Dave Ahlberg, MidAmerican Energy's Product Manager of Industrial Energy Efficiency Programs, stated: "We want to be a good resource for our customers and advisor for SSL projects, offering grants or incentives to help prove market acceptance of the technology."

For SSL, utilities will also need to be creative in designing new rate structures that

preserve the diversity of street-lighting ownership options now offered to municipalities. Utilities like the controllability features of SSL, which allow lighting-optimization strategies for different municipal applications and have a natural fit into the industry's vision of the "smart grid."

Utilities strive to achieve reliable electricity service and high customer-satisfaction scores. Consumers look to their electricity provider for leadership and education on emerging technologies that save energy. Good measurement and validation provides customers with the unbiased facts on the results that new technology can deliver.

Dairy – FreeStall Barn: 250-watt metal-halide conversion to 120-watt LED

	Average Illuminance		MAX		MIN		Max/Min		Coefficient of Variation		Uniformity	
	MH	LED	MH	LED	MH	LED	MH	LED	MH	LED	MH	LED
Photopic	2.3	3.4*	10.4	8.1	0.2	0.4*	101.5	20.3*	.94	.61	11.6	8.4*
Scotopic	4.2	4.9*	20.3	12.0	0.2	0.4*	203.0	30.0*	.99	.63	21.0	12.3*

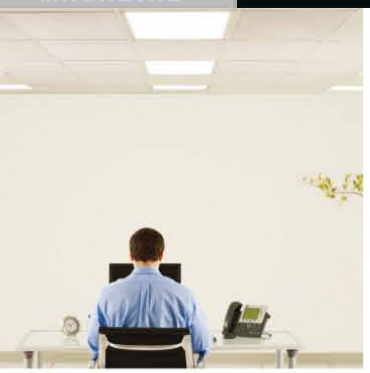
*Denotes matched or better performance

TABLE 2. Photometry comparison of high-bay metal-halide (MH) lighting versus LED in a dairy facility. Data represents 95 measurements on 12x12-foot grid.

Conclusion

SSL has significant market potential, but it is still in the critical early stages of its development. Product success depends upon the market taking a system-engineering approach and evaluating the individual technology components as an integrated product that provides a variety of customers with an important and complex energy service. Market participants must also support customer decisions by tempering product claims with solid real-world test results, as well as designing products and services that provide optimal value by listening to the customer.

Manufacturers, service providers, municipalities, electric utilities and end users all have a stake in the success of SSL technology. Getting the innovation right is more important today when word of failed expectations can reach so many decision-makers very rapidly. However, we can indeed leverage SSL's future market potential to transform lives and position the economy to move forward.



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LEDs enable an optimal near-infrared sensing system

Today's high-efficiency, low-cost, near-infrared (NIR) LEDs and lasers enable many commercial applications. A few straightforward formulas can help the designer approximate the performance of an NIR sensing system and then optimize it to best handle the real-world variables of a particular application, as **ROLF WEBER** explains.

Specifying the best near-infrared (NIR) system for a particular sensing application can be complex but, armed with an understanding of the basic principles and a few straightforward equations, the designer has a good chance of success. Systems based on the NIR range (850-950 nm) of the light spectrum are becoming increasingly popular in a variety of diverse applications such as security and surveillance, data communications, automotive and manufacturing to name a few. Some of the more interesting applications for NIR include adaptive cruise control in automobiles, fingerprint and iris recognition in security systems, and gesture recognition in gaming, medical and home-entertainment applications.

The three main areas that need to be addressed in designing a typical NIR system (Fig. 1) include:

- the emitter or light delivery system, sometimes called the radiator or irradiator, which may be based on an IR LED or a laser,
- the target, which is the object of interest irradiated by the emitter subsystem,
- the light detector or sensor (camera or photodiode based), which measures the amount of light reflected back from the target.

Successfully approximating the light intensity that will ultimately reach the sensor requires an understanding of each link in the light chain between emitter and sensor. There are three critical questions to be answered for any application. For a given emitter in a given application, how much light power or beam flux (in mW/cm^2) arrives at the target? How much of that is reflected back to, and captured by, the sensor? Finally, is the level of light sufficient to reliably collect the information required for the application?

It can be useful to set up a test system with all the real-world variables of the application to answer these questions. Fig. 2 shows an unprocessed video frame from such a system, useful as a benchmark to determine how much light might be required in other applications. The target in this system is a flower pot with 10% reflectivity, placed 94 feet away from the camera in the center of a completely dark scene. The scene is illuminated by two 850-nm Dragon IR LEDs with a secondary ±8° lens, generating about 1W of light. The sensor is an IR web camera with a visible-light cut-off filter running at 20 frames per second.

Applying the calculations that we will detail in this article to this benchmark application yields results of 0.7 µW/cm^2 arriving at the target, and 0.01 µW/cm^2 arriving at the sensor.

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Characterizing the emitter

The first step in characterizing a system is to calculate how much flux (φ) is in the emitted beam, which depends on various factors such as the emitter type, package type and, if present, secondary optics. In general, the light intensity (I) from a source varies with the beam angle (α). So to calculate flux, we must integrate the intensity over the solid angle of the beam.

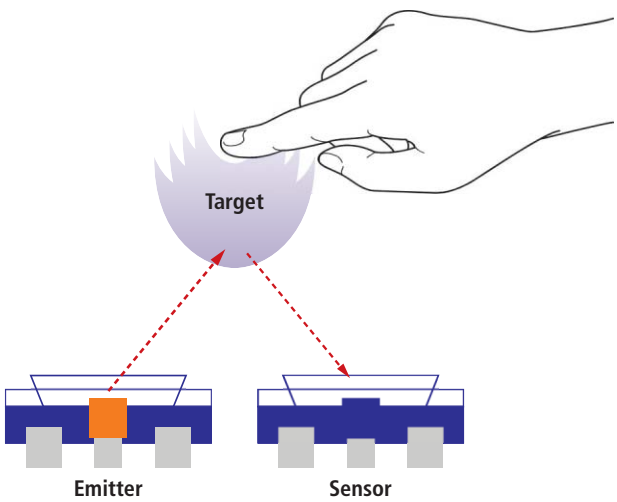

FIG. 1. The three critical components of an NIR sensing system are the emitter, target and detector (or sensor), all affecting the amount of light used in the application.

Solid angles are expressed as a steradian (Ω), which is defined as the surface portion of a sphere hit by the beam divided by the surface of the whole sphere. The steradian for a given beam angle can be calculated with the formula below:

$$\Omega(\alpha) = 2\pi \int_0^{\alpha} \sin\beta \, d\beta$$

The flux in a beam with a ±α beam angle is expressed by the integral of the light intensity over the solid angle, as shown here:

flux φ(α) within beam = $2\pi \int_0^{\alpha}$ (Intensity sin β) dβ

Solving this integral over 90 degrees shows the relationship between intensity at the beam center (I_0), or peak intensity, as well as the total produced flux. Note that peak intensity will vary with the type of light emitter being used, with very different results for Lambertian (0 to 90 degree) emitters compared with emitters equipped with secondary optics such as lenses, diffusers and reflectors.

FIG. 2. Setting up a test system as a benchmark can be helpful in characterizing performance and manipulating variables, such as distance, to see the effect this has.

For a Lambertian emitter such as a lens-less LED, the peak intensity is total flux divided by π *($I_0 = \varphi$ total/ π)*. Flux, in turn, is calculated as follows: $\varphi(\alpha) = \pi I_0 \sin^2\alpha$.

In contrast, for a cosine power-n ($\cos^n$) described lens, peak intensity increases by a factor of n + 1 divided by 2 *($I_0 = \varphi$ total(n + 1)/2π)*. Flux is calculated as follows: $\varphi(\alpha) = 2\pi I_0(1-\cos^{n+1}\alpha)/(n+1)$.

For a given Lambertian emitter whose intensity drops to 50% at a 60° angle, the example cosine power-n lens for n = 10 results in a 50% drop at about a 21-degree angle, reducing the effective beam size. Note also that a secondary lens alone may collect as little as 15% of an LED's emitted light. This can, however, be boosted to 90% or higher when a reflector around the LED is added to the lens.

Light on the target

Once the amount of flux delivered by the emitter subsystem has been approximated, the flux hitting the target can be calculated, as follows:

Flux on target $\Phi = \eta 2\pi I_0 (1-\cos^{n+1}\alpha) / (n+1)$.

The beam angle (α) is determined by the size of the target as seen from the irradiation source. The η variable is the efficiency of the lens. For small alphas, the formula for a lensed LED can be simplified by multiplying the target area with the peak intensity and dividing it by the square of the distance between the emitter and the target, as shown here:

$\Phi = \eta I_0$ target area / distance^2

For a 15° lens (n = 20) and a target size of ±1.5° (that's about a 1 foot target at a 20-foot distance), this simplification causes an acceptable error of less than 0.5%.

Reflected light

The next step in the light chain is the beam power in the reflected light from the target, which is dependent on the size of the target, its reflectivity, and other factors. How much light does a camera need? Setting up some hardware – i.e. an LED emitter subsystem – and establishing the target distance can quickly indicate whether sufficient light can be captured by the sensor.

Reflectivity, which can be specular (mirror-like) or diffuse, must also be considered. For specular reflections, the outgoing light angle equals the incoming angle. Diffuse reflectors, in contrast, are Lambertian light sources, reflecting light in all directions. A real-life target is typically a combination of both reflector types.

Specular reflectors can provide irradiance in the range of 1/(2× distance of target)^2. For

small targets, specular reflection provides more light than diffuse reflection if the target is vertical to the beam. The beam intensity simply drops with the inverse square of the total light path length.

The irradiance provided by diffuse reflectors, in turn, is described by cosine alpha. For a small target, this can be replaced with just the peak intensity value (I_0). For a ± 3° target area, like a 1-foot target at a 10-foot distance, there is only a 0.14% difference using the approximation.

The path to the sensor

The final link in the light chain is the path to the sensor, which may be a simple photodiode (essentially just one big pixel) or a high-resolution camera, based on CCD or CMOS sensors. When both the emitter subsystem and the target have been characterized, the question is whether enough beam flux (mW/cm^2) is supplied to let the sensor see what it needs to see. What is the sensor's criteria and does the rest of the system provide it?

Photodiodes usually aren't implemented with a lens and so collect light from the entire target, in contrast to cameras, whose lenses focus on the light from a selected part of the target.

Photodiode irradiance can be calculated as follows:

Photodiode irradiance = radiance × target area / distance^2

A camera-chip lens system is typically far more efficient than a photodiode without a lens. For example, where a target area has a diameter of one tenth of its distance from the sensor and the camera has a 1.2 lens number, the camera would receive about 70 times more mW/cm^2 than a photodiode without a lens.

FIG 4. An SFH 4232 Platinum IR Dragon emitter.

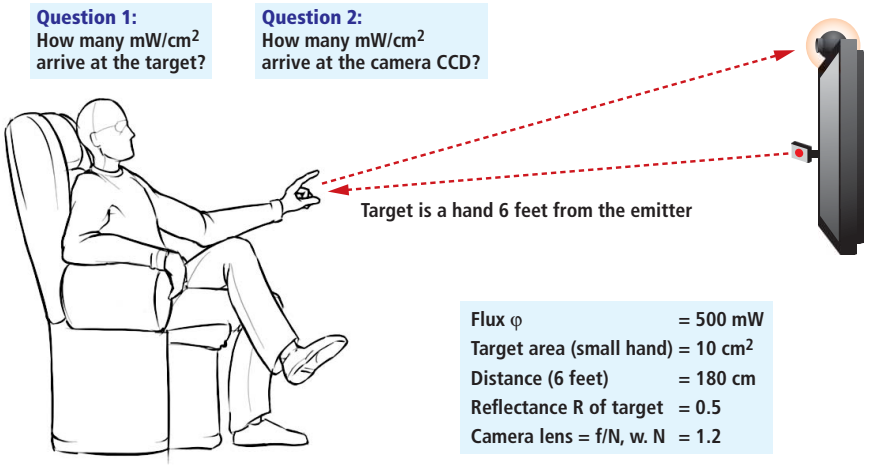

FIG. 3. Parameters of a gesture-recognition system as an example of an NIR sensing system.

It's important to note that cameras have detection limits, and that NIR wavelength has a profound effect on camera sensitivity. Lens apertures, further limit the amount of light cameras can collect, and the camera's focal length, in turn, limits the size of the target picture. Therefore, the irradiance of a camera chip is:

Camera irradiance = 0.25 π (radiance from target) × aperture^2 / focal length^2.

Note that zoom lenses increase the focal length and might reduce the aperture. In the best case, the brightness is reduced by the square of the magnification only.

Also note that the beam flux delivered to a camera is not dependent on the distance from the target. Rather, if you increase the distance, the picture simply gets smaller, leaving the amount of mW/cm² the same.

Wavelength	Visibility (relative units)	CMOS or CCD sensitivity (relative units)
850 nm	10000	10000
900 nm	450	8400
950 nm	30	3600
980 nm	7	2400

TABLE 1. Camera sensitivity decreases at longer NIR wavelengths, but so does a potential problem with undesirable visibility to the naked eye.

The choice of NIR wavelength also comes into play in terms of whether the light is visible to the human eye and sensitivity of the sensor. Table 1 includes sensitivity data. In covert applications, the relative visibility of 850-nm light can be an issue. With increased NIR wavelengths, CCD camera sensitivity drops, but eye visibility drops faster. At longer wavelengths such as 950 and 980 nm, unwanted visibility is drastically reduced.

Gesture-sensing system

Now it is time to put some real-life numbers into the equations to characterize an example of a gesture recognition NIR sensing system. In Fig. 3, a man sits in an easy chair interacting with his TV using gestures. The SFH 4232 Platinum IR Dragon emitter (Fig. 4) located on the side of the TV produces 500 mW of light with a ± 60° beam. The target is the man's hand, 10 cm² in size, 6 feet (180 cm) away from the TV and 50% reflective. The sensor subsystem, which is located at the top of the TV, is a CCD-based camera with a 1.2 lens number.

How much of that original 500 mW reaches the target at the first link of the light path? We can use this formula:

Φ (target) = target area × flux / (π × distance²)

The peak intensity of a Lambertian LED is flux divided by π, so we divide the intensity by the distance squared to get the mW/ cm² at the target. Plugging in the specifics of the example application – a 10 cm² size target, 500 mW IR emitter, and 180 cm distance – we get Φ (target) = 0.05 mW as the result.

The next step is to calculate how much of the remaining beam flux, which has been reduced from 500 mW to just 0.05 mW at the target, will be reflected to the camera. Assuming the target is a diffuse reflector acting like a Lambertian light source, its intensity is the flux divided by π. The flux per cm² is, of course, the received flux per cm² times the reflectivity of the target. The radiance of our example target is 0.8 μW/cm², calculated as follows, with R representing the reflectivity of the target:

Radiance from target = 0.05 mW × R / (π 10cm²) = 0.8 μW / (cm² sr)

Keeping in mind that the focal length divided by lens aperture is the lens number of a camera, we can now calculate the mW/cm² that reaches the camera chip by multiplying the radiance by 0.25 π and multiplying it with the square of lens aperture divided by focal length (the equivalent of dividing 0.25 π by the square of the lens number):

mW/cm² (at CCD) = 0.25 π (radiance from target) × aperture²/focal length².

The result for our gesture-recognition system example is 0.43 μW/cm² at the camera chip, which is an easily detectable light level.

A few straightforward formulas can help the designer approximate the performance of an NIR sensing system and determine what changes may be needed to better handle application variables.

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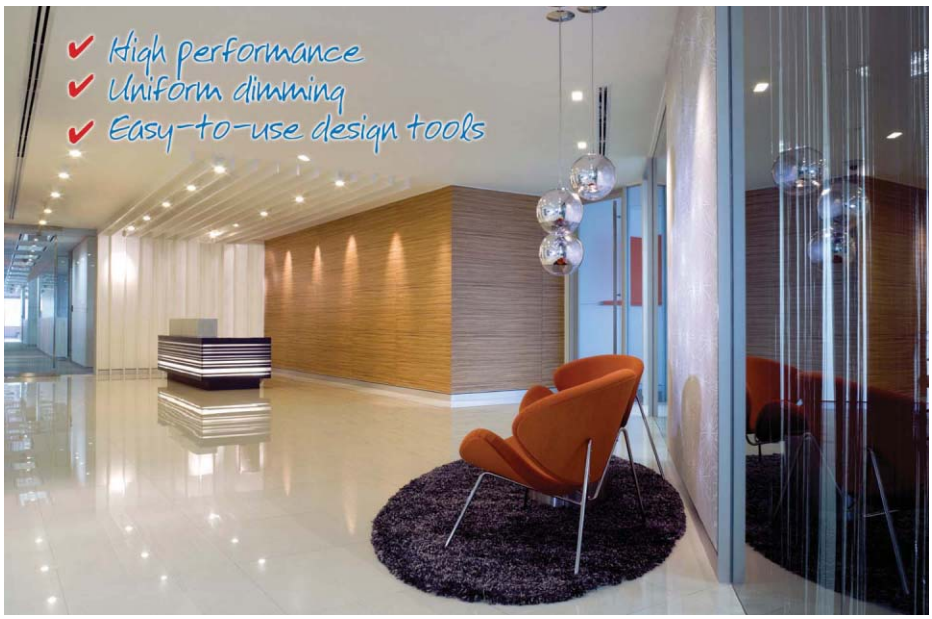

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The LM3450 phase dimmable LED driver integrates active power factor correction and phase dimming decoding, and is ideal for dimmable LED fixture applications with output powers between 10W and 100W and accepts universal input voltages. It features unique dynamic hold circuitry which allows for excellent dimming performance.

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Semicon West delivers technology update on LED manufacturing

A day-long LED session at semiconductor tradeshow Semicon West addressed efficiency droop, MOCVD developments, new packaging schemes, and epitaxial layer transfers, reports **MAURY WRIGHT**.

An LED-centric theme continued to simmer at Semicon West, the annual semiconductor-industry tradeshow that took place July 12-14 in San Francisco, CA. The manufacturing-oriented event included a day-long LED program presented in the Extreme Electronics pavilion called "More lumens per dollar: Issues and answers to bring costs down to create a general lighting market." Speakers from LED manufacturers, equipment manufacturers, materials companies, universities, and analyst organizations addressed efficiency droop, MOCVD developments, new packaging schemes, and even novel epitaxial layer transfers that could all lead to more affordable solid-state lighting (SSL).

LED manufacturing technology was still decidedly in the minority on the huge show floor given the breadth of the show focus. The LED session provided broad coverage that introduced the SSL concept and opportunity to the semiconductor crowd, while also digging deeper into manufacturing better, less-expensive LEDs for the SSL converts in the crowd. We'll skip the details on LED market opportunity and SSL basics here as we've covered those topics extensively – for example in our Strategies in Light coverage – and will focus instead on LED manufacturing.

Identifying droop culprit

Manos Kioupakis, a postdoctoral researcher at the University of California at Santa Barbara (UCSB), presented university research focused on identifying the cause of the droop phenomenon in LEDs. Droop has long puzzled the high-brightness (HB) LED community. At low currents, LEDs can exhibit efficacy well in excess of 200 lm/W, but at the high drive currents used for HB LEDs in general-illumination applications, the efficacy drops considerably. Indeed phosphor-converted white LEDs being shipped today are generally in the 100 lm/W range with some besting that number.

Companies have achieved much better performance in the lab. For instance, Cree announced lab tests that delivered 231 lm/W efficacy earlier this year (www.ledsmagazine.com/news/8/5/8). Solving the droop problem and producing such highly-efficient LEDs is a key to much-lower-cost SSL products and therefore much broader deployment.

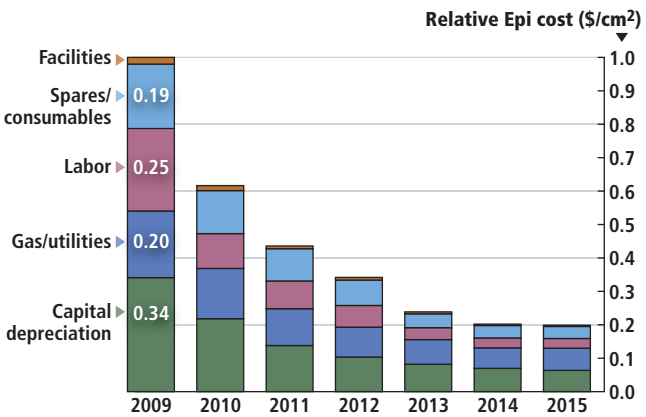

FIG. 1. Veeco projects significant reductions in epi cost.

The UCSB researchers don't claim to have solved the droop problem but to have identified the cause. Indeed researchers have long debated the cause. The leading theories are carrier leakage and Auger recombination. Carrier leakage occurs when charge-carrying electrons escape the active quantum-well region in an LED where light is produced. Auger recombination is a complex phenomenon found in semiconductors where energy is transferred among three carriers with the third ultimately losing the energy that, in the case of LEDs, would generate light.

Kioupakis and his team performed a theoretical evaluation of Auger loss. The key finding according to the team is that indirect Auger loss is the major culprit. Indirect Auger loss is caused by the scattering of charge carriers whereas most other research on the phenomenon has focused on direct Auger loss that has been judged to have a relatively small impact on efficiency.

Presuming their identification of the droop cause is correct, the team is now trying to solve the problem. The researchers believe the answer lies in reducing carrier density through thicker quantum wells, more quantum wells, and nonpolar and semi-polar growth.

Reducing MOCVD costs

Bill Quinn, chief technologist at Veeco Instruments, focused his presentation on trends in MOCVD (metal organic chemical vapor deposition) systems that can reduce the cost of making HB LEDs. Quinn said, "The color, the brightness, and the electrical properties are all determined by the MOCVD." And of course MOCVD tools impact device costs significantly since as Quinn said the tools make up more than 50% of the capital expenditure on a new LED fab.

MAURY WRIGHT *is a Senior Technical Editor with LEDs Magazine.*

The MOCVD tool or reactor handles the epitaxial growth, typically on sapphire wafers, that is the first step in LED chip manufacturing. The reactor mixes precursors – hydride molecules such as ammonia (NH_3) with metal-organics such as trimethylgallium (TMGa) – at the surface of the wafer to grow first an n-type gallium nitride (n-GaN) layer, followed by a multiple quantum well (MQW) region where the light is generated, and topped with a p-type GaN layer.

Despite the high cost, Quinn said that MOCVD remains the best choice for manufacturing LEDs compared to other deposition technologies. He noted the readily-available precursors and high GaN growth rates as advantages and said the tools are easily scalable to 8-in wafers.

The key to lower cost is faster epitaxial processing. Companies such as Veeco have attacked that problem by developing reactor chambers that can handle more wafers simultaneously – as many as 54 2-in wafers in Veeco's case. They are also offering clusters of two to five chambers than can share infrastructure, such as the precursor supply, thereby lowering the total cost of ownership.

Quinn said that Veeco had researched other challenges to reduce prices, and yield takes the number one position. In the case of LEDs, yield doesn't mean an LED that works or doesn't. Rather it means manufacturing an LED that meets tight specifications in color, brightness, and forward voltage.

Veeco has found that better temperature and chemical-flow control can improve yields. In one new approach to better temperature control, the company is using a pyrometer to monitor temperature at the growth layer rather than relying on wafer temperature.

FIG. 2. Dow Electronic Materials' Vaporstation system.

Quinn projects steady progress in MOCVD reactors. He said, "By 2015, continuing on the path we're on with MOCVD improvement, we can get down to a relative epi cost of about 20% of where we were in 2009." (See Fig. 1) That translates to a 3× to 4× reduction in LED cost over the same period, said Quinn.

Centralizing precursor delivery

Thiloma Perera, director of marketing at Dow Electronic Materials, discussed a different approach to optimizing reactor throughput. Dow has developed what it calls a Vaporstation (Fig. 2) that enables centralized vapor-phase delivery of precursors to multiple reactors.

Today, most reactors rely on chemicals stored at each reactor or cluster in metal cylinders that are commonly called bubblers. According to Perera, that approach wastes floor space, increases labor costs, and creates downtime. The reactors must include temperature-controlled baths in which the bubblers are stored – these significantly increase the footprint of the system.

But the larger problem comes when a chemical runs low. Perera said, "You have to stop your reactor, change the bubbler, and then start it again. This takes anywhere from 4 to 24 hours." The long restart time is in part due to the time it takes to stabilize the process.

Dow's approach eliminates this downtime. There are many possible configurations that can support varying numbers of reactors or clusters. But in any scenario there is always a secondary supply of the precursor that takes over when one runs low. Perera said that one customer is running 11 reactors on one Vaporstation.

Perera admitted that it will take time to bring about the cultural change within LED

manufacturers, who would have to transition from a system that has worked successfully. But she insisted it will reduce the cost of ownership of a reactor through lower labor costs and better throughput. Perera said savings from using the centralized system would be highly dependent on each installation. However, Dow believes the system could save $200,000 to $300,000 in operating cost per reactor per year, and that a throughput improvement would come on top of those savings.

Perera also said that the centralized system is safer since most of the precursors are pyrophoric, meaning they will spontaneously ignite if exposed to air. She said that every time a bubbler is changed there is a potential for an accident that would be greatly lessened by moving to a centralized system.

Dicing and packaging

Taking a much broader look at the cost of making LEDs, Yole Developpement senior market and technology analyst Eric Virey presented 20 research areas that could deliver significant advancements in either lower manufacturing cost or better LED performance (meaning essentially more lumen output). He identified larger-diameter wafers and alternative substrates such as silicon as having the most potential for big cost reductions. Solving current droop, as discussed earlier, ranked as having the most significant potential on the performance axis.

Virey, however, chose to focus his presentation on three other areas where there's near-term potential for gains on both axes:

- Die singulation
- Wafer-level packaging
- Thermal management

There are four primary methods now used for die singulation – blade dicing, laser dicing, diamond scribing, and laser scribing. The scribing methods require a breaking step once the scribing is completed.

Improvement can come in several ways according to Virey. Manufacturers could use more-accurate dicing techniques to reduce the street width – the wasted area between LEDs on a wafer – and therefore increase the number of die per wafer. Faster cutting speeds would increase throughput. And techniques are needed that don't damage components and impact yield. Virey said some of the laser schemes can damage the edges of the die causing kerf loss and reducing brightness.

Virey identified a couple of laser-based approaches that might bring about improvements. He noted that to increase throughput, you can't just use a higher laser-dicing speed because that requires higher laser energy and results in component damage. Instead you can split a laser beam creating a serial or in-line multibeam. He also described a parallel system where multiple beams scribe dicing lines simultaneously. He said a 6× improvement in scribing speed would yield double the wafer throughput.

In the thermal-management area, Virey showed examples from all of the major LED vendors in terms of packaging and materials that can conduct heat away from the LED. He moved quickly to a focus on wafer-level packaging (WLP) that it turns out addresses both thermal and packaging issues.

WLP is a concept intended to optimize the back-end of the LED manufacturing process. You still must singulate the LED die, but then bond each to a silicon packaging wafer. The manufacturer can then perform phosphor coating, optic installation, and other processes to a wafer of LEDs rather than one by one before the individual components are once again separated.

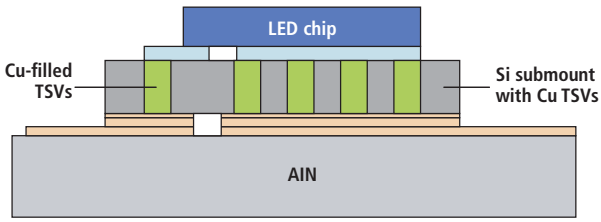

FIG. 3. An LED after transfer to a conductive substrate. Courtesy of Brewer Science.

Virey said that WLP can decrease cost and increase reliability based on monolithic assembly, silicon thermal conductivity, and copper-filled through-silicon vias (TSVs) to connect the anode and cathode, and to provide heat conduction. However, he also said that TSVs add expense. Note that at Semicon West, ESI announced a new packaging system that uses a laser to drill TSVs (www.ledsmagazine.com/news/8/7/15).

Epi layer transfer

TSVs were also a key theme for Ram Trichur, director of the LED/Energy Devices strategic business unit at Brewer Science. Trichur focused on thin-wafer-handling technology. According to Brewer, it can be advantageous to transfer the epitaxial layer from the growth substrate to an electrically- and thermally-conductive substrate. Doing so provides even current distribution through the MQW active region, and better heat dissipation. And a manufacturer can reuse the growth substrate after transferring the epi layer.

To enable such a transfer, the manufactured wafer is bonded temporarily to a carrier wafer attached to the epi side. The original substrate is then removed, and the epi layer is attached to a new substrate made from copper or a metal alloy. Brewer makes the tools and materials that enable the temporary bond t o withstand chemicals and high-temperature processes. The technology allows safe removal of the carrier with no damage to the components.

Trichur showed a sample application in which the LED chip is ultimately mounted on a silicon sub-mount or interposer layer (Fig. 3). Copper-filled TSVs provide both electrical and thermal conductive paths. The silicon layer is mounted to the alloy layer such as aluminum nitride (AlN). Trichur said that Brewer has a new alpha-stage technology called ZoneBond that will allow debonding at room temperature and support wafers as large 300 mm.

Precision tools support critical PSS metrology from R&D through high-volume LED fabrication

The different capabilities of the atomic-force microscope and the white-light interferometer are well suited to the metrology demands of high-brightness LEDs built on patterned sapphire substrates, explains **XIAOMEI LI**.

Growing demand for high-brightness (HB) LEDs is prompting manufacturers to refine production methods and to develop devices with better performance. Achieving these ends requires precision metrology tools. In particular, critical metrology includes measurements of film thickness, and layer and substrate roughness, as well as detailed validation of patterned sapphire substrates (PSS).

This article describes two types of gauge-capable metrology tools that are currently used for these purposes: the atomic-force microscope (AFM), and the white-light interferometer (WLI). Because of its very high speed, the WLI in particular is poised to become a key quality-control (QC)/process-monitoring tool as production volumes of relatively new devices are pushed to ever higher levels. We compare and contrast these very different tools, showing where each is particularly well suited in the HB-LED life cycle of development through volume production.

PSS benefits

In conventional gallium nitride (GaN) on sapphire LEDs, total internal reflection – due to the large refractive-index difference between GaN and air – limits the amount of light that can be extracted from the device. Overcoming this limitation will enable HB-LED manufacturers to steadily increase two of the most important performance parameters – brightness and efficiency.

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Several methods have been developed to enhance the light-extraction efficiency, including random surface texturing, flip-chip technology, photonic crystal and PSS (see Fig. 1). The latter is becoming widely used because of several key advantages, in addition to its higher extraction efficiency. First is cost, since the PSS features can be readily produced on conventionally-polished sapphire wafers using well-proven photolithographic methods. Second is performance related; PSS supports the formation of higher-quality GaN epitaxial layers that can deliver brighter output. Specifically, the GaN layers are prone to dislocation effects due to lattice mismatch issues between the layers, as well as thermal expansion differences. The PSS structures act as a grid that minimizes the formation of these defects and can be conical, hemispherical, or pyramidal (Fig. 2).

Final LED performance is strongly impacted by the quality of the substrate and the various layers. Key factors are the front- and back-side substrate wafer roughness, the roughness and uniformity of the various epitaxial layers, and the absence of defects in these epi layers, such as steps and pinholes. In the case of PSS, it is equally vital that the sapphire bumps are created with the correct dimensions (height and width) and the right pitch; testing protocols must ensure that malformed bumps or missing bumps are avoided.

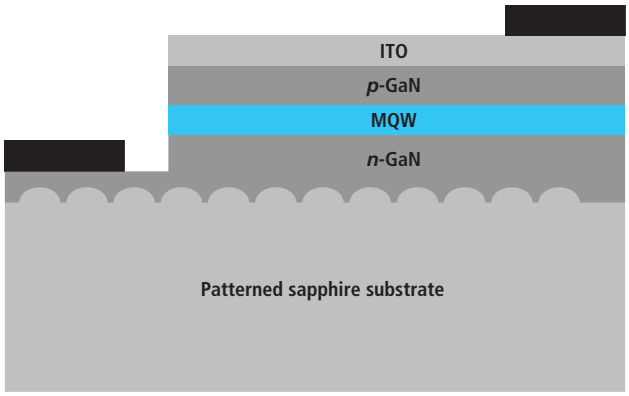

FIG. 1. A typical LED is based on a stack of GaN-based layers grown epitaxially on a sapphire substrate. A patterned sapphire substrate (PSS) can improve the light extraction efficiency.

AFM: the ultimate surface-metrology tool

The highest-resolution surface-metrology instrument available is the atomic-force microscope (AFM). It is now widely used by both wafer suppliers and LED manufacturers as a reference standard because it is capable of atomic resolution.

In AFM operation, a hyper-fine tip on the end of a micro-fabricated cantilever is brought into near-contact with the sample surface. The tip is affected by atomic/molecular interaction forces with the sample surface, which are initially attractive, and then

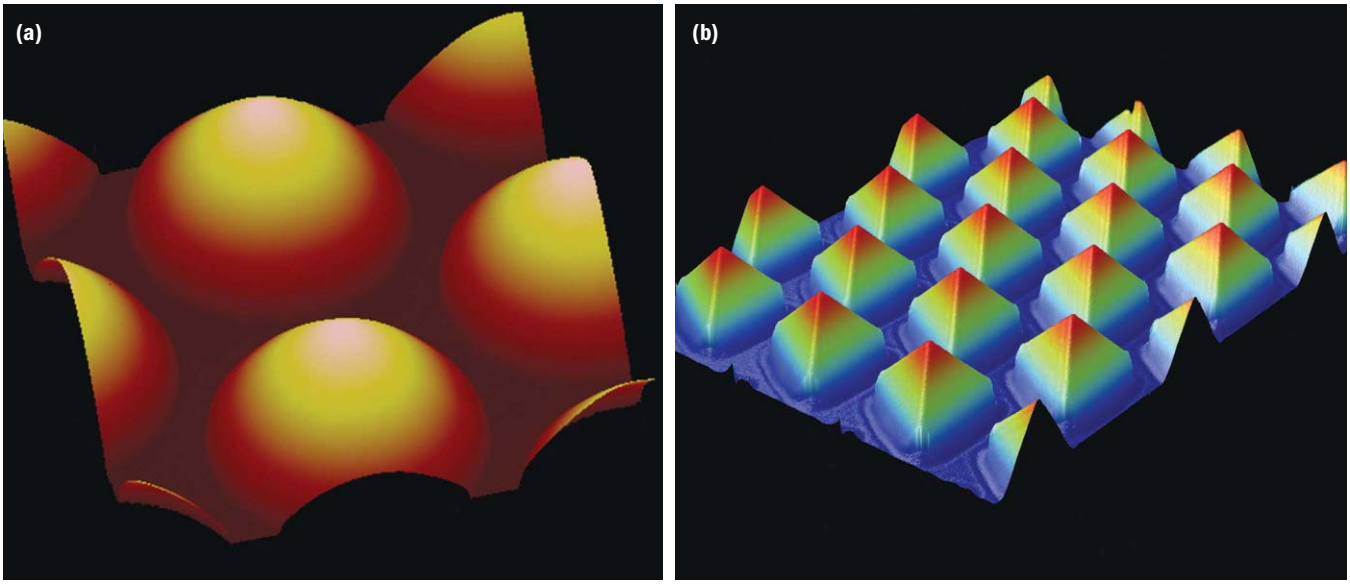

FIG. 2. The exact PSS design varies by manufacturer, but typical structures can be conical, hemispherical, or pyramidal. (a) Data obtained with an AFM (Bruker Dimension Edge PSS). (b) Data obtained with a WLI (Bruker Contour GT-X8 PSS).

become repulsive as the tip contacts the surface. A laser beam measures the position and movement of the cantilever.

By raster-scanning the tip across the sample (or the sample under the tip), a quantitative topographic map of the surface can be created. The in-plane (or XY) resolution is mainly limited by the radius of the tip, and it is often 2 nanometers (nm), or sometimes even better. The resolution in the vertical (Z) dimension is not directly related to the tip, and is often better than 0.5 angstroms (0.05 nm).

Substrate (wafer) suppliers rely on the AFM in particular to measure the results of their polishing process, which has a target R_A (rms) value of 0.5 angstroms (Fig. 3). Widely used in many industries and applications, R_A is the arithmetic mean of all deviations from the mean surface height. While the AFM is limited by its modest measurement speed, 100% sampling is not required for these applications. This is because the polishing process is deterministic and well-characterized, so process sampling need only be statistical. Similarly, for LED manufacturers, heavy testing of conventional smooth wafers from well-qualified vendors is not considered necessary, and the AFM is the dominant and preferred tool.

The AFM is also the definitive reference for the production of epitaxial layers. The XYZ metrology it provides is ideal for spotting film defects, such as steps and pinholes. It is also fast enough for measuring the roughness of these layers during new process development or modification, where its non-destructive nature is a significant advantage. And, once a process is proven, it is often the preferred tool for statistical sampling of final product.

However, in the production of textured wafers, and most notably those with PSS, the picture is somewhat different. The details of the PSS surface are vitally important but cannot yet be produced with 100% yield, meaning that ideally every PSS wafer is sampled and preferably at several locations on each wafer. For example, even small amounts of wafer bow can de-focus the lithography process in certain parts of the wafer.

For R&D and some production applications, the AFM is still the preferred tool for PSS because it provides complete three-dimensional characterization of the critical surfaces, including slope, at atomic resolution if necessary. Indeed AFM manufacturers such as Bruker have developed dedicated AFMs for PSS applications (e.g. the Dimension Edge PSS). These tools combine the ability to automatically measure up to nine 2- to 6-inch wafers at a time with software that supports dual (engineering and operator) levels of access. This latter feature enables an engineer to set up measurement protocols as well as pass/fail criteria and then hand the tool off to a technician as a simple pass/fail diagnostic.

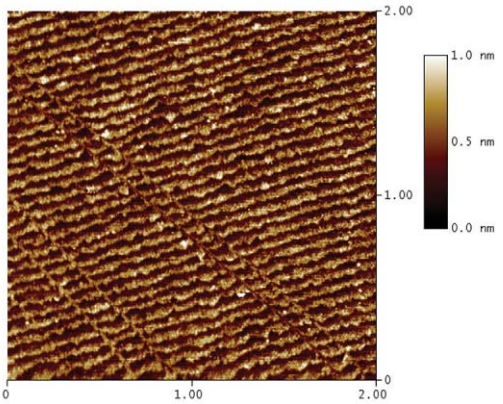

FIG. 3. The AFM is capable of full three-dimensional resolution. This example is a 2 x 2-µm surface-profile scan of a polished sapphire wafer measured with a Bruker Dimension Edge PSS.

WLI supports high-volume PSS

For very-high production volumes, even AFMs designed specifically for PSS can be a testing bottleneck. The white-light interferometer (WLI) is a tool that better meets the needs of these applications. Specifically, the WLI can quantify the height, width and

FIG. 5. A dual white-light interferometer (WLI) implementation with integrated wafer handling for the sapphire substrates speeds production testing.

pitch of PSS features and readily spot defective features. In addition, it is an ideal tool for measuring surface roughness and the thickness of optically-transparent films that are greater than 1.5 µm in thickness.

The WLI, or optical profiler, is a non-contact, non-destructive tool that uses light waves as a high-resolution ruler or depth gauge. A WLI looks similar to a conventional optical microscope, and the device under test is placed on the sample stage. Light from a white-light source is sent into the objective, and is then split into two paths by a partially-reflective mirror. One of the paths is focused on the sample surface and the other is deflected to an extremely-flat internal reference surface. When these two reflections are recombined, the image contains a series of dark and light bands that are a direct function of the profile of the test surface; they are analogous to elevation contours on a topographic map. Moreover, they only appear as sharp stripes in the image where the microscope is perfectly focused on that part of the sample.

In operation, the instrument's computer steps the microscope through a full range of focus positions and captures the shape of these band contours on a digital camera, also noting the precise focal depth at which each part of the striped image is sharpest. Onboard software then uses this data to calculate a three-dimensional surface map over the entire field of view in a few seconds, i.e. tens of thousands of surface points (pixels) simultaneously versus a point-by-point tool such as the AFM. This very high speed makes WLI an optimum platform for high-density (e.g. 100%) sampling even in a very-high-throughput production environment.

The WLI delivers extremely high dynamic range; that is, it provides vertical resolution of better than 0.1 nm over a range of feature heights up to 8 mm. In the (horizontal) XY plane, WLI image resolution depends on the choice of microscope objective. In addition to mapping the surface profile and features (Fig. 4), a high-performance WLI can also compute common statistical parameters such as R_A roughness.

The WLI is already proving to be a robust tool for several different HB-LED metrology tasks including ITO (indium tin oxide) film roughness; GaN film thickness measurement; PSS pitch, width, height and uniformity; PSS defect inspection (non-valid peaks); and sapphire substrate top- and bottom-side flatness.

However, it is in the areas of profiling PSS wafer pitch, width and height, as well as defect inspection, that the WLI's speed is proving to be a critical advantage.

The seamless integration of this testing modality within the PSS production environment requires more than just performance and speed. It also requires automated wafer handling, technician-level software operation, and customizable statistical analysis and archiving. A new generation of WLIs has now been developed specifically for PSS work. Such WLIs integrate these key practical features, together with software algorithms required to fully optimize PSS feature size measurement. An example of this is the ContourGT-X8 PSS from Bruker, which enables highly repeatable, high-throughput, nanometer surface metrology of HB-LED PSS. Integrated with a CHAD WaferMate wafer-handling system, this QC tool supports turnkey operation for production QC environments and seamless integration with automated substrate handlers. Furthermore, maximum speed can be doubled by using a dual-WLI setup, as shown in Fig. 5.

The optimum WLI magnification for PSS work appears to be about 230×, which delivers the best combination of field of view (i.e. speed) with the XY resolution required for pass/fail operation and process feedback. For example, the 20 micron^2 field-of-view per measurement enables 13 such sites to be analyzed per 2-inch wafer in just 2 minutes. This corresponds to more than 60 wafers per hour.

Depending on the HB-LED specifics, a 20 micron^2 field-of-view corresponds to between 20 and 100 PSS features. Moreover, the standard deviation of measured height is less than 6 nm (3σ), and less than 10 nm (3σ) for width. The use of automated internal calibration means excellent gauge capability; the 3σ standard deviation of height, width, and pitch is less than 10 nm over a five-day period.

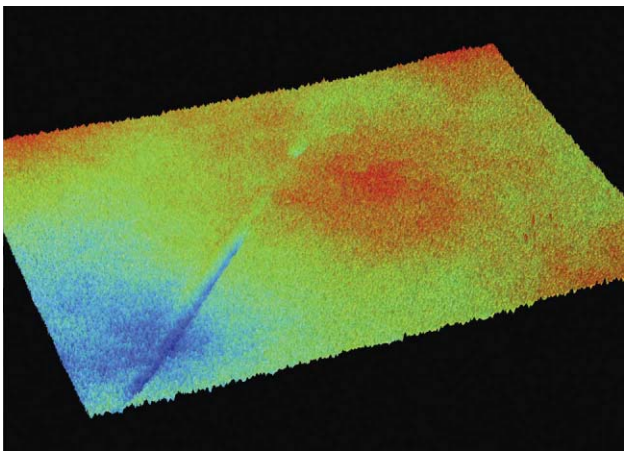

FIG. 4. WLI roughness measurement of a sapphire substrate, showing a polishing scratch. Field of view is microns.

Conclusion

For conventional LEDs, the AFM remains the ultimate surface-metrology tool for LED fabricators and wafer vendors alike. It's also an ideal solution for development and qualification of new production processes, such as for PSS HB-LEDs. But when these HB-LEDs go to very-high-volume production, dense sampling can often be better served by a WLI. This is a versatile tool that is also useful for other HB-LED QC/metrology tasks including surface roughness and gauging thickness of optically-transparent films.

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Advanced analysis and control systems could multiply yields in LED manufacturing processes

Significant yield enhancements in LED fabrication can be achieved by the integration of yield analysis, fault detection and classification, and run-to-run process control, says **MICHAEL PLISINSKI**.

As demand for high-brightness LEDs continues to accelerate, manufacturers are turning to a potent combination of yield analysis, process control, equipment monitoring and factory automation to increase output, optimize profitability and gain strategic advantage in an increasingly competitive marketplace. While each of these components brings specific benefits, when intelligently integrated, their total combined benefit is far greater than the sum of their individual contributions.

Historically, LED manufacturing has suffered from low overall yields and even lower binned yields of devices with specific characteristics. High yield variability further complicates the problem, introducing significant uncertainty over time and making it difficult to maintain a nimble yet reliable supply chain for customers. As the market matures, it is no longer economically viable to simply buy more capacity, and competitive advantage will shift increasingly to those who can improve yield and increase output through more efficient use of existing assets.

In addition to rapidly-growing demand, other trends in the industry are also increasing the pressure to improve yields. These include demand for larger LEDs in a single package; the need to reduce assembly costs and reduce losses to "street waste" (between die); as well as increases in the number of die per wafer, resulting from smaller die and larger wafers.

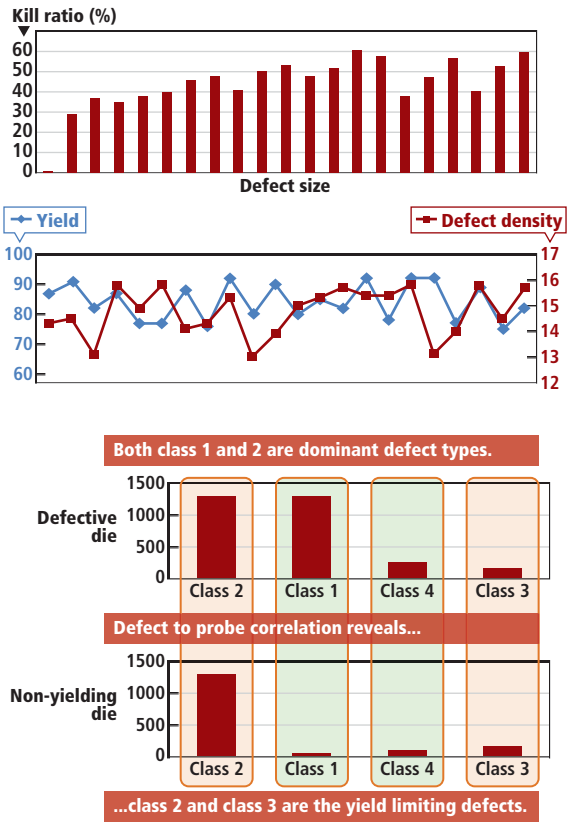

FIG. 1. Data show little correlation between defect lethality and defect size (top) or density (middle). After image-based automatic defect classification, a very strong correlation appears for the specific defect classes 2 and 3 (bottom).

Early efforts at LED process control focused on substrate inspection before, and electrical test after, the fabrication process. It was essentially a go/no-go approach, having the primary goal of detecting faulty devices and avoiding the additional cost of packaging them. The path to greater yields requires a more pervasive, fully-integrated solution. This includes yield analysis, to rapidly identify root causes and reduce wafers at risk; real-time equipment monitoring, to quickly detect faults and reduce costs of ownership; and precise process control, to optimize processes and increase binning yields. All of these components should communicate through a comprehensive factory automation and data collection facility.

Yield management

Yield management provides the capability to analyze defect, metrology and test data across the entire process. Input data should be collected as widely as possible, including inspection and metrology tools, equipment sensors and event logs, manufacturing execution system (MES) scheduling and tracking data, and final test yields.

Given sufficient input, yield analysis can quickly determine where the root cause of a problem lies - incoming material, equipment malfunction, or process excursion. It

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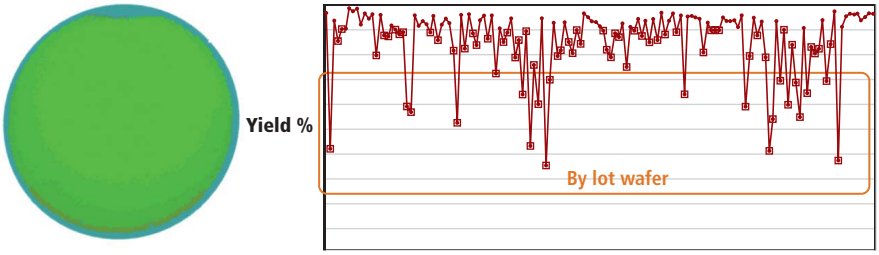

FIG. 2. By stacking defect maps from over 1000 low-yielding wafers and applying spatial pattern recognition, yield analysis reveals a problem in a bonding process.

allows engineers to prioritize their efforts on those problems that have the greatest effect on yield. Once a cause is identified they can drill down further to equipment-performance data, formulating procedures to prevent future process problems.

Although much of the methodology for LED yield analysis can be adapted straightforwardly from integrated-circuit manufacturing, LED manufacturing also poses a number of unique challenges. These include the ability to process data from broken or partial wafers, the precise alignment of maps among various tool sets, and the ability to simultaneously analyze thousands of wafer maps each with hundreds of thousands of die.

As an example, consider the problem of assessing the yield impact of specific defects. A reasonable starting assumption might be that the size of the defect determines its lethality, though the data presented in Fig. 1 show only a weak correlation between size and "kill ratio." Neither is there a discernible relationship between defect density and yield. However, using image-based automatic defect classification (ADC) to sort the defects into classes with similar characteristics, it becomes clear that almost all defects in classes 2 and 3 are killers, while those in classes 1 and 4 have almost no impact on yield. This allows the process engineers to adjust the tool process to eliminate specific defect types to improve overall yield.

In the second example, engineers were challenged to find the cause of sporadic low-yielding wafer lots. The yield management system (YMS) allowed them to select over 1,000 wafer maps from low-yielding lots and stack them to look for tell-tale patterns in the defect data. The maps first had to be aligned to correct rotational errors of plus/minus several degrees that result from the "one-shot" exposure technique used for LED fabrication. Then, using algorithms specially designed to recognize wafer-scale spatial patterns,

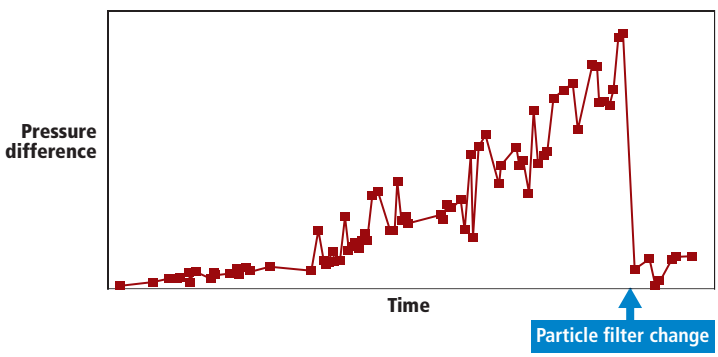

FIG. 3. Increasing difference between process and exhaust pressures on an MOCVD tool indicates a need to service the exhaust filter before a fault condition occurs.

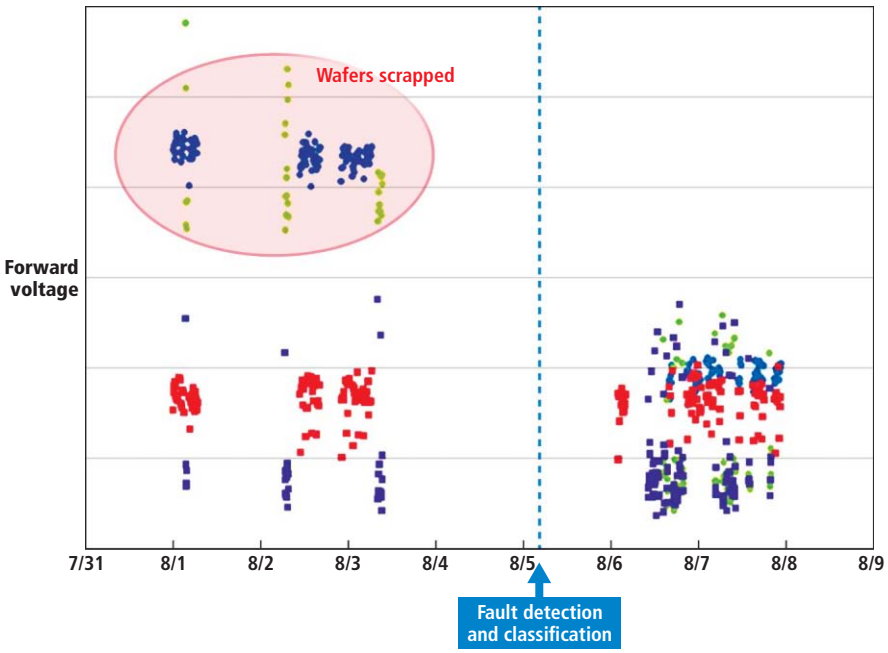

FIG. 4. A CVD tool problem resulted in 138 scrapped wafers and 3.5 days of downtime. A fault detection and classification (FDC) model was developed to detect the fault condition on the first wafer.

they were able to trace the problem to the bonding process (Fig. 2). The entire analysis, which would likely have taken several days to perform manually, was completed in less than two hours.

YMS can also be used to correlate yield with event-type data such as changes in recipes, equipment maintenance, SPC alarms and more. Quantitative data on the yield impact of these occurrences, which may include aggregate data from multiple sources, provides a sound basis for operational decisions, such as the optimal frequency of periodic maintenance procedures. Periodic reporting and charting focuses engineering resources on important yield-robbing issues. Automatic alarms can trigger customized reports that drill down through the data to reveal underlying causes.

Equipment monitoring

Real-time fault detection and classification (FDC) tools analyze hundreds of data points per second to monitor equipment performance. Using this data, it constructs models to predict process performance based on the monitored parameters. Engineers can use the models to detect abnormalities before they become faults. Automatic characterization of faults reduces trouble-shooting time. Accurate models also allow the optimization of maintenance schedules to provide maintenance when, and only when, it is needed, avoiding unnecessary downtime and minimizing cost of ownership.

On a typical MOCVD tool, monitored parameters might include: reactor and exhaust pressure – for filter maintenance cycles, baratron calibration, device failure; MFC/PC stability – for time-to-settle variations, bubbler health for condensation/depletion; and reactor heating – for temperature stability, filament aging, and reactor cooling. In Fig. 3, an increasing difference between reactor and exhaust pressure signals the need for filter maintenance before it causes process problems.

Fig. 4 demonstrates the value of real-time FDC on a CVD tool. Without real-time monitoring, 138 wafers were misprocessed before the problem was detected and it took 3.5 days to locate and correct the fault. An FDC model was developed that detected the fault on the first misprocessed wafer, informing engineers of the exact nature of the problem to speed repairs.

In yet another example, engineers

were able to retrieve and compare pressure data from a normal chamber and a low-yielding chamber. Overlaying the data (Fig. 5) clearly indicated pressure differences between the chambers and led them to replace a malfunctioning valve on the defective chamber.

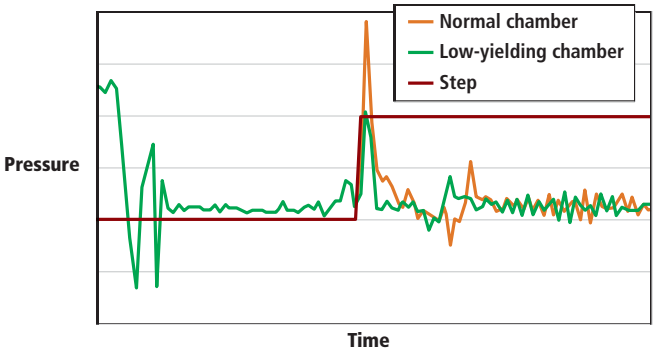

FIG. 5. Overlaying pressure data from a normal and a non-yielding process chamber revealed obvious differences and led rapidly to the replacement of a malfunctioning valve.

Process control

By monitoring drifts in process performance from run to run, engineers reduce process variation and drive performance to optimal values. Possible applications include control of film thickness, composition, and uniformity; critical dimensions of metal lines; the accuracy of pattern overlays; and thermal uniformity during the growth of multi-quantum wells. Automation of run-to-run measurements and adjustments reduces engineering time and eliminates operator errors in the calculations. Avoiding rework and increasing the time between replacements also improves the cost efficiency of consumable parts and supplies.

Chemical mechanical polishing (CMP) processes remove material from the wafer surface using a chemically-reactive, abrasive slurry and a polishing pad. The material removal rate changes as the pad ages. By measuring the removal rate of the process combined with feed-forward thickness information and feeding this information back to modulate down-force and polishing time for the next run, engineers were able to reduce film-thickness variability, center variations about the target value, and maintain the process entirely within control limits (Fig. 6).

Similarly, run-to-run process control was used to improve control of the sputter-deposition process, in which depletion of the sputtering target leads to changes in deposition rate. Measurements of deposition rate are fed back to adjust deposition time. Control of uniformity and resistivity can also be improved by feeding back data to adjust gas flows and RF power.

Factory automation

The final piece of the puzzle is provided by the factory automation system, which coordinates the data flow between operators, equipment and factory systems. It provides communication among all systems and components in the factory, including user interfaces and credentials, engineering enquiries and reports, process control systems, data collection interfaces, process equipment, operational settings and recipes, databases, and incoming material entry. The implementation of well-designed automation layers significantly reduces the time to implement advanced analysis packages, such as fault detection and run-to-run control systems, and virtually eliminates scrap due to operator error.

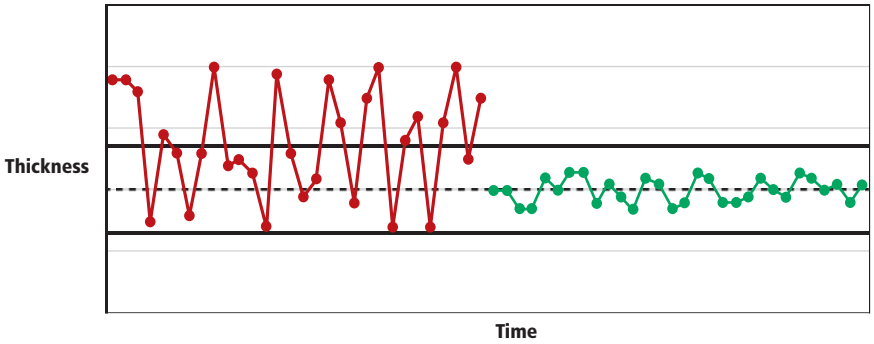

FIG. 6. Run-to-run monitoring of a CMP process uses feedback of current removal rates and incoming thickness to adjust polishing time and down-force for subsequent runs. This reduces variability, centers the distribution on the target value and eliminates out-of-spec performance.

Conclusion

Comprehensive integration among the various components – yield analysis, fault detection and classification, and run-to-run process control – is the key to maximizing returns on investment in process control. Yield analysis, including automatic defect classification and spatial pattern recognition, permits the rapid identification and prioritization of yield-reducing problems and their root causes. Fault detection and classification permits predictive modeling to detect abnormalities and trends before they impact yield. Run-to-run process control allows feedback of current process performance to adjust operating parameters, achieving better control and tighter process windows. Moreover, all of these technologies can scale inexpensively to accommodate additional process capacity.

Given that some current LED manufacturing processes have yields less than 40% and binned yields less than 20%, yields could double and binned yields could quadruple and still be at levels well below those of advanced IC manufacturing processes.

Although there may be unknown practical impediments to achieving such yields for LEDs, the mere possibility of such dramatic increases in productivity, with only modest investments in control systems and little or no investment in additional process equipment, is sufficient to stimulate intense interest among manufacturers.

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design forum | **DRIVING STRINGS**

Brighter LEDs can simplify driver designs

LED vendors are producing components that can operate at higher drive currents and produce more lumens, and system designers can move to a simpler two-stage driver as the number of LEDs in a fixture is reduced, explains **BERNIE WEIR**.

Much attention in the LED lighting world has focused on two applications that are at polar extremes; low-power incandescent bulb replacement and high-power street lights. While these applications are ubiquitous and iconic, there is also a range of area-lighting applications – such as parking garages, park lighting, stairway lighting – and outdoor commercial lighting – such as wall packs, wall washers, and security, flood, gas-station canopy and pathway lighting – which are hiding in plain sight. These medium- to high-power applications are ideal candidates for solid-state lighting (SSL), and new LEDs that operate at higher drive currents and produce more lumens are a good match. Designing a luminaire with fewer brighter LEDs can also simplify the driver electronics and ease the task of adding adaptive controls.

The applications mentioned above are a good match with LEDs, because they consume large amounts of power, have high hours of annual use, and are used in public spaces that may not be occupied for many hours, thus opening the door for adaptive controls and dimming that can significantly reduce energy consumption. Beyond energy cost, a driving factor of LED lighting is long life and reducing the maintenance cost of bulb replacement.

Traditionally, the aforementioned medium-power applications have used high-pressure-sodium (HPS) and metal-halide (MH) light sources. HPS light sources are actually very efficient but generate a decidedly yellow/orange light that has very poor color rendering since the light source is nearly monochromatic.

MH sources display better optical characteristics but have slightly lower initial lumen output, shorter lifetime, and higher lumen degradation over the useful life. MH lifetime (measured to 50% failure point of the population) is in the 10-20,000 hour range depending on the bulb design and construction, whereas HPS has typical lifetimes of 24,000 hours.

HPS and MH sources are also limited in terms of adaptive controls and dimming. And most of these area-lighting applications require directional light. Although HPS and MH bulbs have high lumen output, 40-60% of the generated light can be lost in the fixture.

LED life and controls

High-brightness white-LED light sources address many of the limitations of the legacy lighting technologies as they are inherently directional in nature, have very long operating lifetimes, provide white light with good color rendering and, given their instant-on characteristics, are easy to dim across a wide range of light levels. Moreover LED performance has been rapidly improving in terms of lumen output and efficacy (lm/W) and over the last few years has been making in-roads into these traditional area-lighting applications.

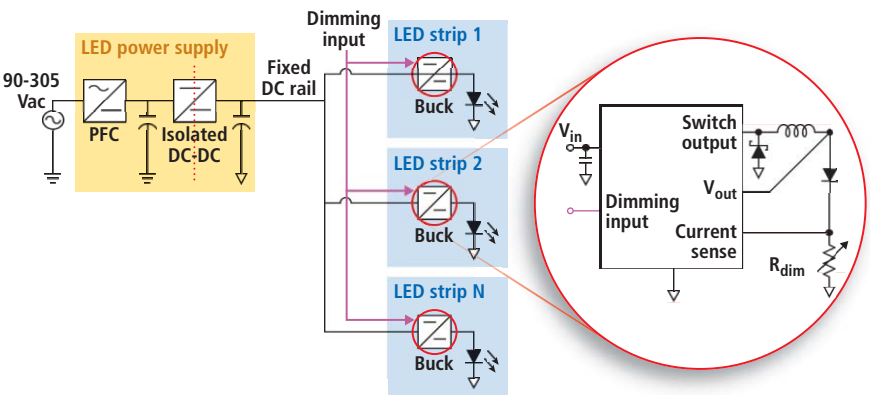


FIG. 1. Three-stage LED driver approach.

When white HB-LEDs came on the market, the most common configuration was called a "1W" LED because when it was driven with 350 mA, it typically dissipated around 1.2W given a nominal forward voltage of 3.3-3.5V. Today, widely-available 1W LEDs can generate more than 100 lumens at an efficacy of over 100 lm/W. To generate 5000 delivered lumens a fixture needs on the order of 50 LEDs whereas 18-24 months ago the same application may have required 80-100 LEDs.

To power such a large number of LEDs from the AC line, drivers have typically used a three-stage power-conversion architecture as illustrated in Fig 1. A two-stage constant-voltage power supply implements power-factor correction (PFC) in the first stage, followed by a high-voltage DC-DC converter

BERNIE WEIR *is the applications and marketing manager for the computing and consumer product group at ON Semiconductor.*

that generates a safe isolated voltage rail typically in the range of 28-60 VDC.

The fixed-voltage output rail supplies multiple strings of LEDs. A third-stage, a dedicated buck DC-DC LED driver, provides regulated current to each string. Depending on the output of the second stage and the forward voltage of the LEDs, each string might include 8-12 LEDs.

Brighter LEDs

Some LED manufacturers have developed advanced processes and improved LED chip designs that deliver more lumens at higher drive currents while maintaining the same forward voltage. For example, the Cree XM-L is rated for up to 3A drive current and has a very low typical forward voltage of 3.1V at 1500 mA drive current. At 1500 mA and 85°C junction temperature, in cool white, each LED generates 440-475 lm. A fixture that uses just 12 such LEDs would have an output in the range of 5200-5700 lm with a typical load power of around 53W, delivering over 100 lm/W efficacy.

Going from 50 LEDs in the previous example to 12 simplifies the optics but it has a more sweeping impact on the driver architecture. Now all the LEDs can be safely driven in a single string, eliminating the need for multiple parallel DC-DC LED buck drivers. This also improves light uniformity as all LEDs are driven at the same exact current.

To eliminate the third stage, the two-stage constant-voltage LED power supply is replaced with a constant-current LED driver. This provides two fundamental advantages. The overall system efficiency is improved as one power-conversion stage is completely eliminated, and the cost and design complexity of multiple DC-DC converters is eliminated. It also simplifies adding intelligent control as the dimming function can now be integrated in the current-control loop of the constant-current LED driver.

Adaptive controls have been used in indoor lighting for a number of years and involve combining sensors with networked or autonomous microprocessor-based controls to optimize the lighting level to the needs of the environment. Simple examples include adding an occupancy-sensor lighting control to turn off a light source when there is no activity for a prescribed time.

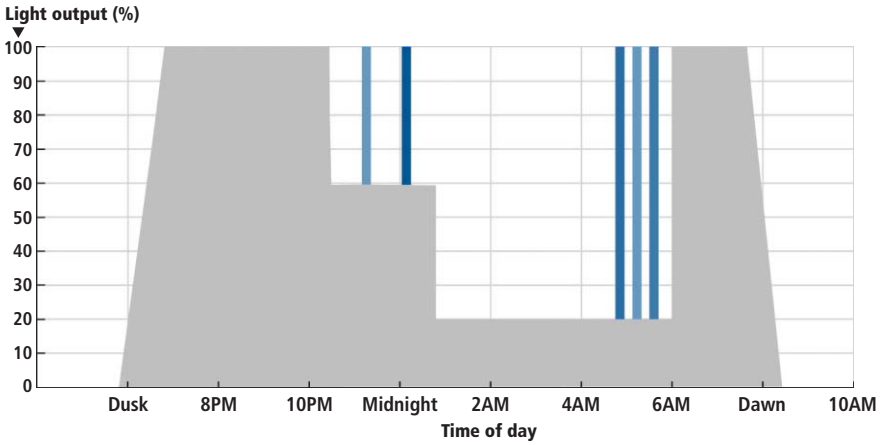


FIG. 2. Example of a smart dimming profile.

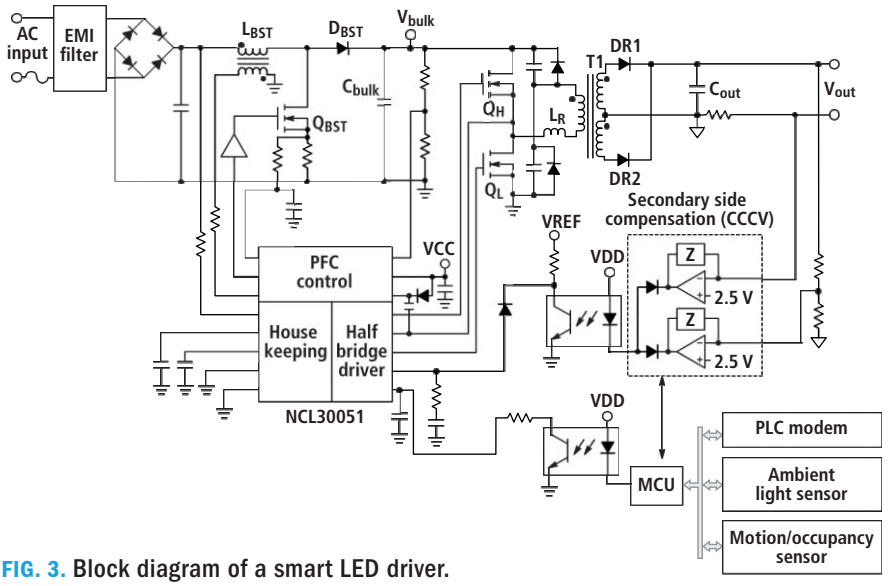


FIG. 3. Block diagram of a smart LED driver.

Control scenarios

In area lighting, controls have been mostly limited to on and off at dusk and dawn. But dimming LED light sources is very straightforward compared to HPS and MH light sources that have long turn-on and restart times. LED light sources can be dimmed across a wide range and can rapidly turn on to 100% brightness based on activity or occupancy. In an outdoor park-lighting scene, for example, this means the light along the running path or walkway can be turned down significantly when no activity is detected and instantaneously turned to full brightness if a jogger runs down the trail in the middle of the night.

Fig. 2 illustrates a possible dimming profile through the course of a typical evening. The gray area represents timer-based control and the blue areas indicate those times that the light source is increased to 100% when activity is detected. The energy savings can be substantial since most of the operating hours are at the reduced energy-consumption levels.

Application trials for such bi-level control performed by the California Lighting Technology Center at the University of California-Davis indicate these control schemes can yield energy savings of as much as 70-90% over traditional HID approaches.

Let's consider an example of how new high-lumen packaged LEDs can simply the luminaire system architecture and efficiently convert AC power into a regulated current in the 1-3A range (Fig. 3). Such an LED driver design can also incorporate support functions to enable adaptive controls. The addition of a

low-cost microcontroller (MCU) opens the door to more-sophisticated control schemes that can monitor ambient light, occupancy/activity sensors, time of day, and day of week to provide appropriate light in a variety of situations while maximizing energy savings.

MCUs and networks add functionality

For centralized control, these smart luminaires can be networked, for example using a power-line-communications (PLC) modem block (Fig. 3). Alternatively, a system can use a wireless interface like Zigbee, a traditional wired interface such as Ethernet, or existing lighting and building controls.

The block diagram illustrates an AC-DC driver based on a high-efficiency PFC and half-bridge-resonant (HBR) isolated DC/DC step-down controller integrated in the NCL30051 from ON Semiconductor. The basic current-control loop consists of a simple analog circuit which monitors the output current and provides feedback across the isolation barrier via an opto-coupler to the primary-side control IC. The circuit also monitors the maximum output voltage, preventing driver damage in the event the LED string is accidentally opened.

The MCU monitors sensor feedback and network communications to control the light level. Moreover the MCU generates a PWM signal that is used to turn on and off the half-bridge driver, thereby controlling the light level. The PFC block implements a critical conduction mode (CCM) control scheme which achieves high power factor (>0.98 typical) with low harmonic content and is suitable for applications up to 200W.

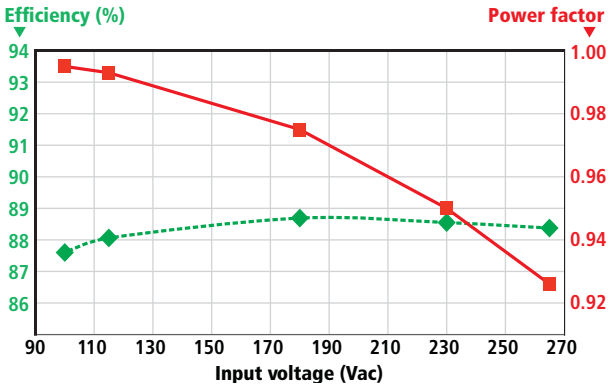


FIG. 4. Typical 55W 2A NCL30051 driver efficiency and power factor.

Efficiency and power factor

This driver architecture can support a wide range of power levels. Fig. 4 illustrates the typical efficiency and power-factor curve of an example driver design based on the NCL30051 driving 2A with a nominal LED load of 55W. Across the 115-240 VAC line-voltage range, the efficiency exceeds 88% and the power factor is greater than 0.94.

The Cree XM-L LED is ideally suited for this range of current. At 700 mA, it generates 260-280 lm (neutral/cool white). A string of 9 LEDs driven at 2A outputs more than 5000 lm. This lumen level can easily address a range of area-lighting applications such as wall packs and wall washers. Depending on the drive current and LED configuration, this type of driver approach can exceed 90% wall-plug efficiency, as well as supporting a range of dimming methods required for intelligent control.

New LEDs that have high source-lumen capability can greatly simplify the LED driver architecture by reducing power-conversion stages and increasing overall power-conversion efficiency. Adding smart controls can yield further energy savings and opens the door to new capabilities such as constant-lumen-output operation modes. Here, the driver can control the LED current to maintain constant lumen output over lifetime to combat lumen depreciation. Smart dimming-control techniques have an additional benefit of extending the operating lifetime of the LEDs as well as the driver electronics by reducing the average operating temperature.

last word

Large-area LED display industry faces pricing and supply challenges

The LED display industry needs intelligent pricing that enables sustainable businesses, as well as a secure supply chain, including reliable LED suppliers, writes **PETER PIHOS** of **EDG RESEARCH.**

The large-area display (LAD) industry has returned to positive growth, at levels comparable to those before the economic downturn. The growth rate is tempered by continued price declines, even though demand is at record levels. Lower pricing of LADs, especially full-color ones, has opened up markets that could not justify the cost before, and this is a good thing as long as products do not become overly commoditized. Even so, this does not mean there will be clear sailing ahead. There are a couple of equally-important challenges, namely intelligent pricing and a reliable supply of components, that should be addressed in the coming years, so that companies may more easily enjoy degrees of financial health and stability.

Intelligent pricing

A number of years ago I developed with John Finlayson, former general manager of Stewart Warner, a pricing model that we felt represented an intelligent way to price an LAD. The key word here is "intelligent," by which I mean "pricing that affords a company the ability to make a profit, thereby enabling a business to have sustainability." Periodically I sit down with my technical guru, Zoltan Helmeczi, who has been involved in manufacturing and sourcing parts for over 20 years, to see if the model still stands the test of time.

To be sure, the model still works for top-tier companies, but is less effective when you look at the lower half of the pricing range offered by some companies. If one were to take the extreme low end of pricing for a 20-mm-pitch system at $750 per m^2 and work the model backwards, there is absolutely no way a company can expect to have a viable business. At that price level, many of my clients (who are mainly LAD suppliers) question how it is possible just to purchase the components (at least the ones low-cost providers claim they are using), much less allocate a portion of the sales price as a contribution to fixed costs.

Pricing has dropped dramatically in the past 15 years from $33,000 per m^2 for a 30-mm system to $1,500-3,000 per m^2 for a 20-mm system. But of course this means proportionally lower revenues and profits for LAD suppliers.

If I were a buyer I would want to be sure that the company I was purchasing from could continue as a business, to be able to assist if there was a technical problem, to have replacement parts readily available for the life expectancy of the system and generally to stand behind the product. With 85% of display production coming either direct or OEM from China, this is very important. The products may be commoditized, but they are not as yet disposable.

So whether you are an OEM customer or an end-user, care should be given when deciding which system you purchase. If not, you could end up like a recent European OEM customer that made a $100k down-payment, only to find the very next week that the company was in receivership and the chances of getting either the money back or equipment ordered were slim to none.

Reliable source of components

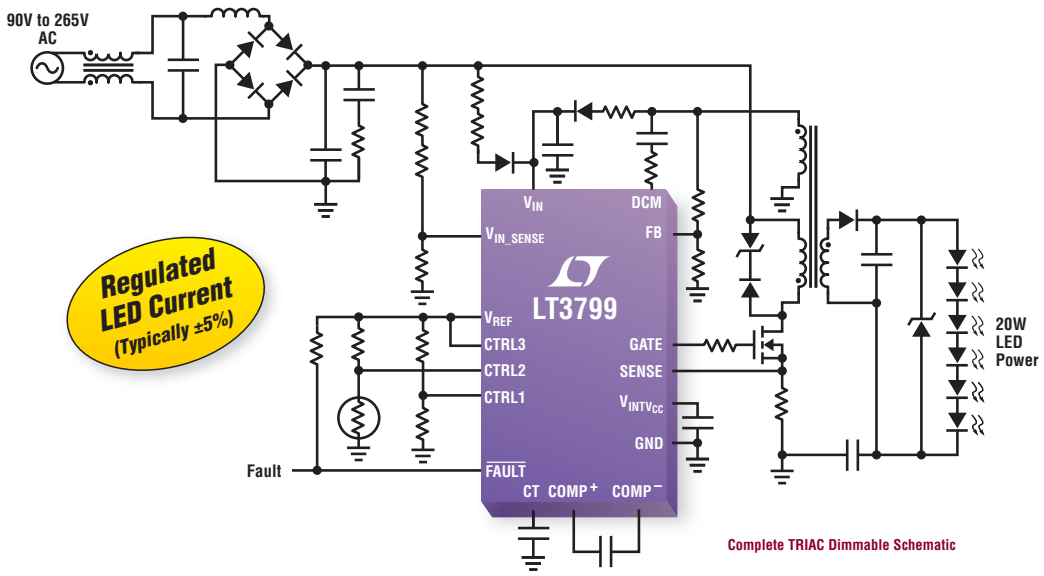
One of the concerns I hear most often from my clients is having a reliable LED supply chain in the future. LAD suppliers feel they will be regulated to second-class status, as their market share of LED consumption will not warrant continued product development for LADs. Granted the end market is very small compared to others, especially lighting, but is still in the region of $1.0-1.5 billion annually.

It is no secret that some display companies have trouble reordering LEDs that they have purchased in years past. With the focus in LED development heavily geared towards lighting, what will happen to the LEDs that are used in LED displays? Will there be advances in LED display component technology that will match the advances found for lighting?

I believe there exists an opportunity for an LED supplier to focus on the LAD market by providing an approach that is different from the past and meets the needs of the future.

MORE: EDG Research (www.edguide.com).

Isolated LED Current Control with Active PFC



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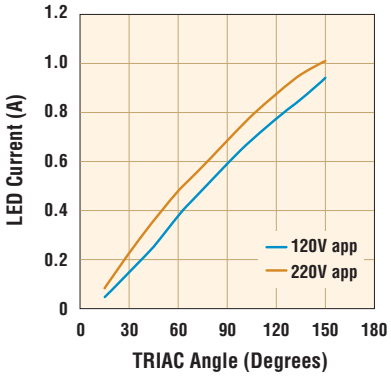
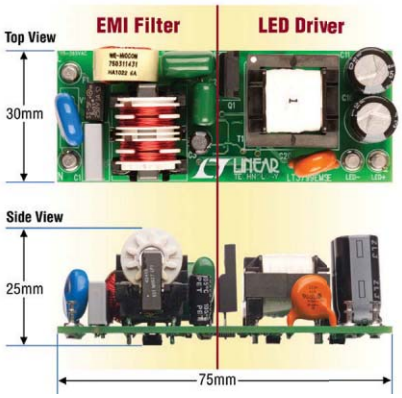
LED Current vs TRIAC Angle



LT3799 Demo Board (25W)



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Cree's full line of RGB and white high-brightness LEDs, with through-hole and surface-mount configurations, deliver breakthrough performance at an economical price. It's no wonder we're leading the LED revolution.

Get samples of Cree High-Brightness LEDs or contact an authorized distributor at cree.com/hb or call us at 800-533-2583.

CREE®

ABOUT STRATEGIES IN LIGHT EUROPE

After a successful launch in September 2010, the Strategies in Light Europe conference and exhibition moves to Milan, Italy, where the event will take place on October 4-6, 2011. The conference programme will address key issues surrounding the evolution and transformation of the lighting market, and the ongoing development of higher-quality, higher-performance LED lighting.

Speakers at Strategies in Light Europe 2011 with focus on issues such as critical challenges & barriers to adoption; case studies and user feedback; regulatory issues & standards; government support & funding; technology updates & roadmaps; the manufacturing supply chain; quality & reliability; and the competitive landscape.

Beyond the conference sessions, Strategies in Light Europe offers a dedicated trade show floor, with numerous exhibiting companies displaying state-of-the-art technology, services, software and hardware. A great opportunity to discover what's new and up-and-coming in the world of LED lighting.

If you are involved in the LED market, you cannot afford to miss Strategies in Light Europe. The event will enable you to make important connections that are key to success in the European and global lighting industries.

We look forward to welcoming you to Milan.

WHY YOU SHOULD ATTEND

LEARN	valuable insights into future directions and strategies that could have an impact on your business from our high profile keynote and leading international speakers.
DISCOVER	the latest products and services within the LED industry that could put you ahead of the competition at our industry leading exhibition.
NETWORK	with your peers and industry professionals at our highly popular networking reception that takes place on the Wednesday evening.
ACQUIRE	new business contacts and opportunities to help move your business forward.
SHARE	experiences, information and tips fellow industry professionals.

SUPPORTING ASSOCIATIONS

CELMA · European Lamp Companies Federation · PIDA · LA The Lighting Association · EPIC European Photonics Industry Consortium · PHOTONICS21

SPONSORS

Registration and Conference Luncheon Sponsor: GE

Conference Sponsor: UL

Conference Pen Sponsor: molex — one company › a world of innovation

Welcome Reception Sponsor: STYRON

Exhibit Bag Sponsor: Intertek — Valued Quality. Delivered.

Conference Padfolio Sponsor: PHILIPS

Conferences Proceedings and Pocket Guide Sponsor: Harvard

DOW CORNING Electronics Solutions

Exhibit Floor Giveaway Sponsor: excelsys · SEOUL

www.sileurope.com

WHO SHOULD ATTEND

Professionals from all areas of the LED & Lighting Industry will attend including:

- The LED manufacturing supply chain
- Members of the lighting industry
- The lighting design community
- Policy makers
- Standards organisations and other key stakeholders

EARLYBIRD DISCOUNTS

Register as a Conference Delegate before 31 August 2011 to take advantage of discounted earlybird delegate rates.

FREE EXHIBITION ENTRY

Pre-register as a visitor before 30 September 2011 for FREE admittance into the exhibition.
After 30 September 2011 you will need to register onsite at the Crowne Plaza, Milan Linate, and will be subject to a €30 fee.

HOW DO I REGISTER?

It's easy to register with one of these 4 ways:

Online registration via the Strategies in Light Europe website is a straightforward and simple process. Just log on to the event website www.sileurope.com and click the online registration link

Mail your completed registration form to us at:
SILE, Conferences and Exhibitions Registration,
PO Box 973059, Dallas, TX
75397-3059, USA

Please complete the registration form and fax it to: +1 918 831 9161

Complete the registration form and email to registration@pennwell.com

HOW DO I GET THERE?

CROWNE PLAZA MILAN LINATE

Crowne Plaza Milan-Linate is just 15 minutes by complimentary shuttle bus from Milan Linate Airport. You'll find the hotel at the head of the A1 motorway, which connects Milan with the heel of Italy, and next to the city's ring road for easy links to Turin and Venice. Nearby San Donato station places you 11 Metro stops from downtown Milan, where finance and high fashion rub shoulders with art by Michelangelo.

★ CROWNE PLAZA HOTEL

www.sileurope.com

CONFERENCE AT A GLANCE

STRATEGIES IN LIGHT EUROPE 2011 PROGRAMME GRID			
Day 1 - Tuesday 4 October 2011			
Tuesday 4 October 2011	09:00 - 12:00	WORKSHOP A - Thermal Management for LEDs & Solid-State Lighting	Solid-State Lighting Investor Forum
	12:00 - 13:00	Delegate Lunch	
	12:30 - 15:00	WORKSHOP B - Light Measurement for Solid-State Lighting	Solid-State Lighting Investor Forum
	15:00 - 15:30	Delegate Coffee Break	
	15:30 - 17:00	Opening Keynote Session	
	17:00 - 19:00	Welcome Reception	
Day 2 - Wednesday 5 October 2011			
Wednesday 5 October 2011	08:30 - 10:30	SESSION 1 - Plenary	
		Market Transformation Track	**Technology Track**
	10:30 - 11:00	Delegate Coffee Break	
	11:00 - 12:00	SESSION 2 - European Initiatives #1	SESSION 2 - Luminaire/System Design
	12:00 - 13:30	Delegate Lunch	
	13:30 - 15:00	SESSION 3 - European Initiatives #2	SESSION 3 - Drivers & Dimming
	15:00 - 15:30	Delegate Coffee Break	
	15:30 - 17:00	SESSION 4 - Standards	SESSION 4 - Networks & Control
	17:00 - 19:00	Networking Reception	
Day 3 - Thursday 6 October 2011			
Thursday 6 October 2011	08:30 - 10:00	SESSION 5 - Market Development	SESSION 5 - Retrofit Lamps
	10:00 - 10:30	Delegate Coffee Break	
	10:30 - 12:00	SESSION 6 - Outdoor Lighting	SESSION 6 - Optical Materials & Packaging
	12:00 - 13:00	Delegate Lunch	
	13:00 - 15:00	SESSION 7 - Lighting Applications	SESSION 7 - Optics

EXHIBITION TIMES

Tuesday 4 October 17:00 - 19:00
Wednesday 5 October 08:30 - 19:00
Thursday 6 October 08:30 - 15:00

OPENING KEYNOTE

Open and FREE of charge to all
Tuesday 4 October 15:30 - 17:00

WELCOME RECEPTION

Tuesday 4 October 17:00 - 19:00

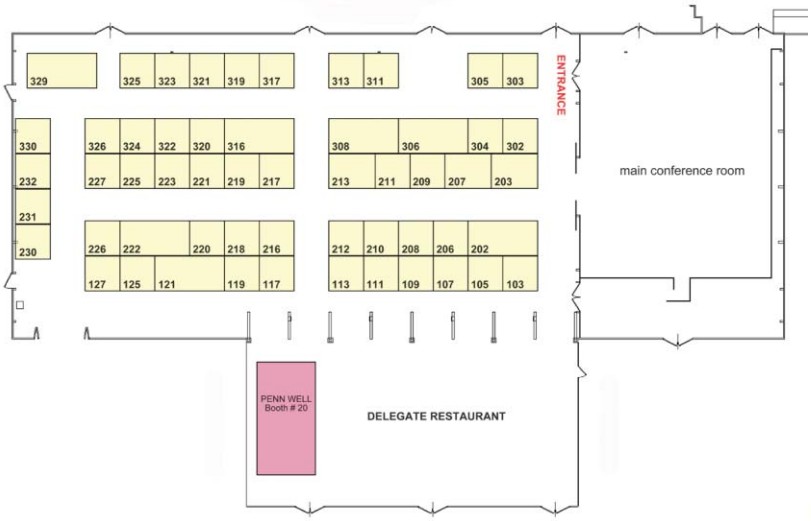
NETWORKING RECEPTION

Wednesday 5 October 17:00 - 19:00

EXHIBITOR PRESENTATIONS

Open and FREE of charge to all throughout the exhibition opening hours

FLOOR PLAN & EXHIBITOR LIST



Exhibitor	Booth Number
AIXTRON SE	216
ALANOD Aluminium-Veredlung GmbH & Co.KG	304
Almeco S.p.A.	206
Avantes BV	223
B&W Tek, Inc	324
Bayer Material Science AG	105
Bayer Sheet Europe GmbH	103
Bergquist Company (The)	109
Carclo Technical Plastics Ltd.	203
Cooliance, Inc.	119
DEKRA Certification B.V.	219
Dilitronics GmbH	231
DOW Corning Europe S.A	325
DSM Engineering Plastics	213
Everlight Electronics	217
Evonik Industries	313
Excelsys Technologies Ltd.	207
GE Lighting	113
GrafTech International	202
Grah Automotive	308
HAMAMATSU PHOTONICS ITALIA S.R.L.	323
Harvard Engineering Plc	121
Instrument Systems GmbH	225
Intertek	321
IST Ltd. (iDrive®)	220
iWATT	127
KHATOD	107
Labsphere Europe	320
LED Japan Conference & Expo / Strategies in Light	20
Ledlink Optics Inc.	211
LEDs Magazine	20

Exhibitor	Booth Number
Light Tec	208
Lightech Electronics Europe	326
LPA EXCIL ELECTRONICS	125
Mean Well Europe B.V.	117
Molex Deutschland GmbH	221
National Semiconductor GmbH	311
NXP Semiconductors	222
Ocean Optics EMEA	305
Optima Research Ltd.	230
OPTIS North America	210
Optogan GmbH	218
OSRAM Opto Semiconductors GmbH	303
OXYTECH Srl	232
PennWell Corporation	20
Philips Lumileds	306
Philips OEM Lighting Solutions EMEA	316
PREMIER FARNELL UK LIMITED	209
RECOM Electronic GmbH	111
RENESAS ELECTRONICS EUROPE GMBH	322
Roal Electronics S.p.A.	317
Seoul Semiconductors Europe GmbH	329
Serigroup Srl	330
Sharp Microelectronics Europe	212
Strategies in Light	20
Strategies in Light China	20
Strategies Unlimited	20
Styron Europe GmbH	319
Texas Instruments Deutschland GmbH	227
UL (Underwriters Laboratories)	302
W.C. Heraeus GmbH	226

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REGISTRATION FORM

PRIORITY CODE

Early Bird Discount
Register before 31st August 2011

PLEASE PRINT CLEARLY

First Name _____

Family Name _____

Position _____

Organization/Company _____

Complete Mailing Address _____

_____

Postal Code: _____ Country: _____

Telephone (+) _____ Fax (+) _____

E-mail _____

CONFIRMATIONS WILL BE EMAILED IF A UNIQUE E-MAIL IS PROVIDED.

Strategies in Light Europe

Conference and Exhibition
4 - 6 October 2011

Crowne Plaza Milan, Linate
Milan | Italy

4 Ways To Register

1. Online: Visit www.sileurope.com

2. By Fax: Fax your completed reg form to: +1 918 831 9161 or toll free (US only): +1 888 299 8057

3. By Mail: SIL Europe Conference & Exhibition Registration, P.O. Box 973059, Dallas, TX 75397-3059

4. By email: Scan in your completed registration form and email to Registration@pennwell.com

www.sileurope.com

CONFERENCE FEES:

Total Access Package – Includes Workshop and Investor Forum (4th October) Conference (5th & 6th October) Conference/Workshops/Investors Forum Proceedings, Keynote Presentation, Exhibition, Welcome Reception, Network Reception, Coffee Breaks and Lunches:

Paid Before 31st August ☑ €950 individual
Paid on or after 31st August ☑ €1110 individual

Individual Full Conference – Conference, Conference Proceedings, Keynote Presentation, Exhibition, Welcome Reception, Network Reception, Coffee Breaks and Lunches:

Paid Before 31st August 2011 ☑ €700 Individual
Paid on or after 31st August 2011 ☑ €750 Individual

Exhibitor Full Conference - (Must be Exhibiting Company) Includes Conference, Conference Proceedings, Keynote, Exhibition, Networking Reception, Coffee Breaks and Lunches:

☑ €360.00

Workshop – Includes access to 1 x Workshop, Exhibition, Welcome Reception

☑ Workshop A
☑ Workshop B

Paid Before 31st August 2011 ☑ €105 Individual
Paid on or after 31st August 2011 ☑ €165 Individual

Investor Forum: Includes access to the investor Forum (4th October), Exhibition, lunch on that day and the Welcome Reception ☑ €105 Individual

Exhibition – Includes access to Keynote, Exhibition Floor, Coffee Breaks, Welcome Reception and Networking Reception only

☑ Free if you pre-register before 30 September 2011
☑ Register Onsite in Milan - €30

Conference Proceedings Only: Download the presentations post show from www.sileurope.com
☑ €105

Payment must be received by published date in order to receive early discount registrations. Registration without payment will not be processed. Company checks must be issued to PennWell/SIL Europe Conference & Exhibition 2011. Credit card payments require card number, expiration date and signature.

Confirmation and Cancellation Policy: No attendee will be admitted into the conference without payment by check, cash or credit card. Any individual, sponsor, or corporate registrations cancelled before August 31, 2011 will receive refund of registration fee less a €100 service charge. After August 31, 2011 no refunds will be permitted. Proceedings will be sent to cancellations made after August 31, 2011. All cancellations must be received in writing. Please note: non-payment does not constitute cancellation. Substitutions may be made at any time by contacting registration office in writing.

PLEASE COMPLETE THE FOLLOWING SECTIONS:

1. TYPE OF COMPANY OR ORGANIZATION: (SELECT ONE)
❑ 01 Designer/Specifier/Installer/End-User
❑ 02 LED module/Sub-system manufacturer
❑ 03 LED Equipment and Instrument Supplier
❑ 04 LED Material and Chemical Supplier
❑ 05 Test & measurement/Standards
❑ 06 LED chip manufacturer
❑ 07 Lighting Fixture or display manufacturer
❑ 08 LED packager
❑ 09 Optics and Optical design
❑ 10 Drivers and Power supplies
❑ 11 Equipment/Materials supply for chip manufacturing
❑ 12 Distribution/Sales representation
❑ 13 Financial and Consulting
❑ 14 Academic or Government research
❑ 15 Media and PR
❑ 16 Other, please specify

2. JOB FUNCTION: (SELECT ONE)
❑ 01 Mgt (CEO, President, GM, VP)
❑ 02 Engineering/Product/Technical Manager
❑ 03 Design Engineer
❑ 04 Architect Lighting Designer
❑ 05 Product Eng & Manufacturing
❑ 06 Corp R&D
❑ 07 Distribution and Sales
❑ 08 Purchasing
❑ 09 Consulting
❑ 10 Investment/Financial
❑ 11 Other, please specify

3. APPLICATIONS AREAS OF INTEREST: (CHECK ALL THAT APPLY)
❑ 01 General Lighting
❑ 02 Entertainment and decorative lighting
❑ 03 Vehicles
❑ 04 Signals
❑ 05 Signs and Displays
❑ 06 Mobile Appliances
❑ 07 Industry and medical
❑ 08 Architect/Lighting Designer/Specifier
❑ 09 Other, please specify

4. WHAT PRODUCTS DO YOU PURCHASE OR SPECIFY? (CHECK ALL THAT APPLY)
❑ 01 LED chips
❑ 02 LED Manufacturing Equipment
❑ 03 Materials and Chemicals for LED Manufacturing
❑ 04 LED modules and subsystems
❑ 05 Packaged LEDs
❑ 06 Chip-on boards
❑ 07 Driver ICs
❑ 08 Drivers and control equipment
❑ 09 Optical design software & services
❑ 10 Test and Measurement equipment
❑ 11 Optics, lenses, diffusers, etc.
❑ 12 Packing materials, heat sinks
❑ 13 Displays
❑ 14 Lighting fixtures
❑ 15 Other, please specify

5. WHAT PUBLICATIONS DO YOU READ TO OBTAIN INFORMATION ON HB LEDS? (CHECK ALL THAT APPLY)
❑ 01 Compound Semiconductor Magazine
❑ 02 LEDs Magazine
❑ 03 CompoundSemiOnline/ SolidStateLighting.net/LIGHTimes
❑ 04 Lighting Design + Application Magazine
❑ 05 LED Journal
❑ 06 Other, please specify

6. PURCHASING ROLE: (CHECK ALL THAT APPLY)
❑ 01 Specify
❑ 02 Recommend
❑ 03 Approve
❑ 04 None

METHOD OF PAYMENT:

Credit card, wire transfer or make cheques payable to PennWell/SIL Europe Conference & Exhibition. Payment must be received prior admittance to the conference.

Please add all selections and total here: €_____

Add 20% Italian VAT: _____ €

TOTAL DUE: _____ €

☑ Cheque enclosed (€)
☑ Wire Transfer (Wiring infomation provided on invoice)

Credit Card:
☑ Amex ☑ MasterCard ☑ Visa

Card number: _____

Exp date: _____

Name on Card: _____

Signature: _____

Date: _____ PennWell®

I understand that my signature authorizes PennWell to charge the above amount to my credit card

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