SEPTEMBER/OCTOBER 2010

LEDs MAGAZINE

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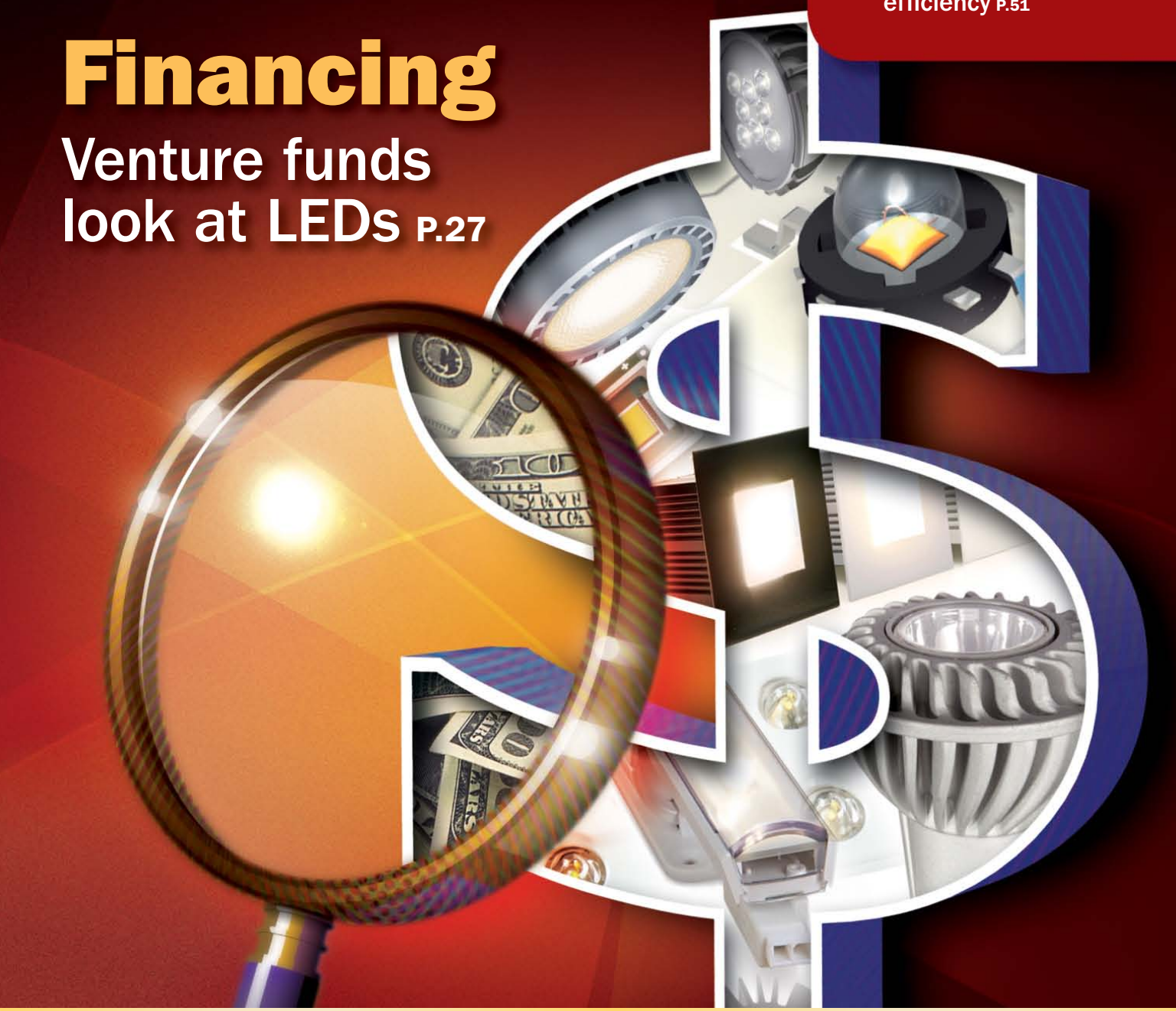

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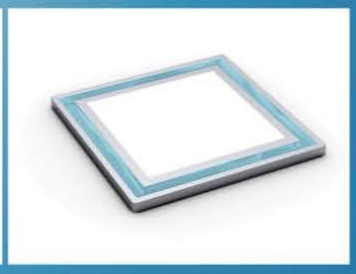

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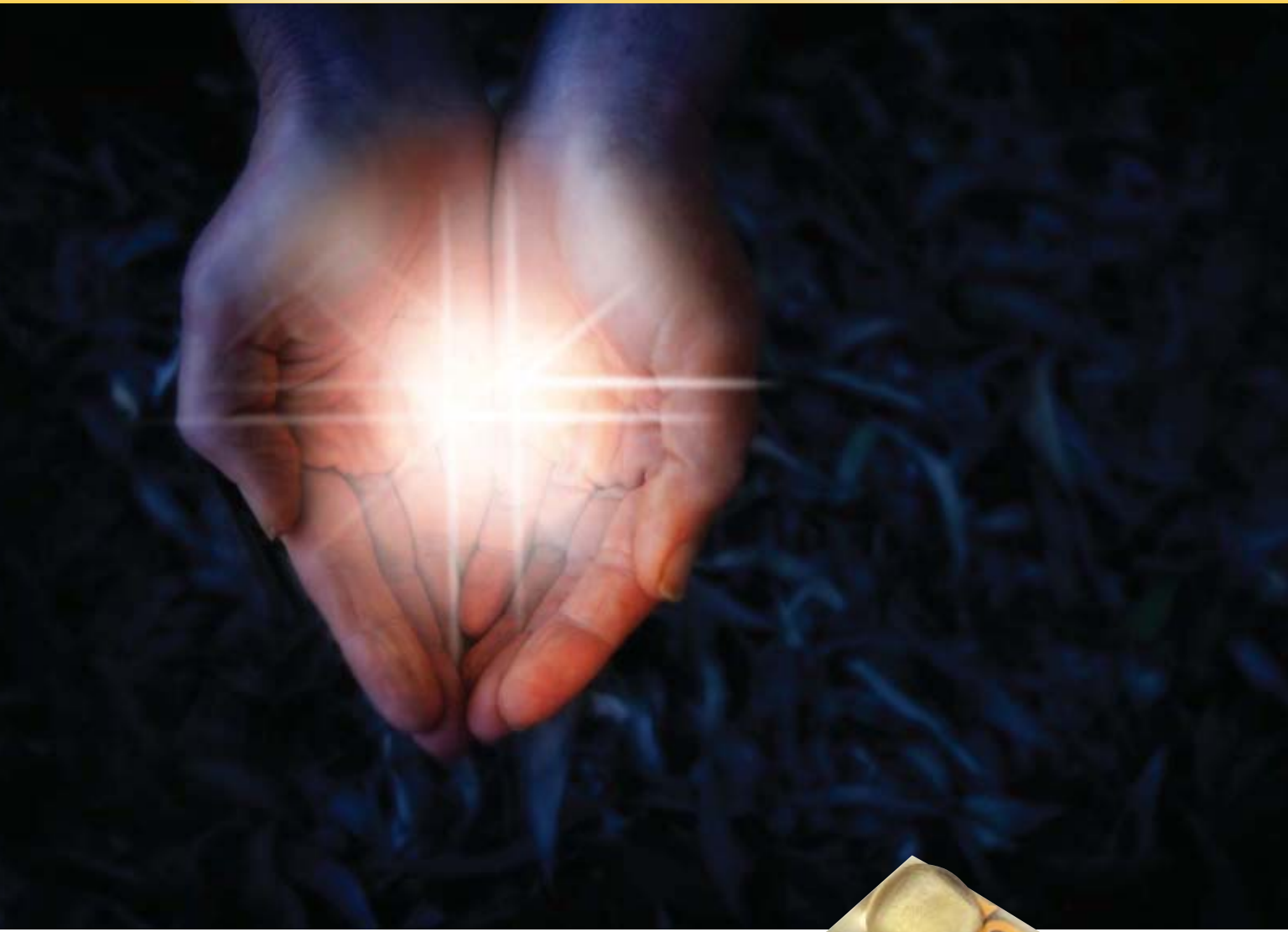

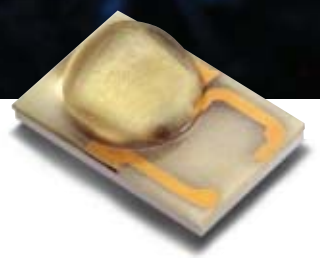

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ISSUE 37

september/october 2010

Cover Story

The LED and solid-state lighting industry is a growing segment of focus for the venture-capital community, as our article from Braemar Energy Ventures explains - see page 27.

features

columns/departments

commentary

Money talks, and LEDs are no exception

The LED industry has been enjoying strong growth in recent months, and this has been reflected in the financial results of the small number of publicly-traded US companies that have a strong LED-related business component. Among these, the most visible is Cree, which had LED product revenue of $240 million in its April-June quarter, up 76% compared with the same quarter last year (page 10). Fellow LED maker SemiLEDs has decided that the time is right to file for an initial public offering, so will likely join Cree on the Nasdaq exchange soon, where it will enjoy the ticker symbol "LEDS" (page 10). Another public company, MOCVD system maker Veeco, recently sold its metrology business to Bruker, so that it can focus on its LED & Solar segment, which will now account for about 90% of its revenue.

The cleantech sector is now seen as one of the strongest areas for investment by venture-capital companies looking for strong returns. Energy generation, including solar, has seen lots of investment in the recent past, while energy efficiency, of which lighting is an important part, has been rediscovered by the venture-capital community. There have been numerous recent examples of investment in companies through the LED value chain, from LED components to lighting controls. But what does it take to attract the attention of the venture funds and make them part with their cash? In his article on page 27, Dennis Costello of Braemar Energy Ventures provides a series of tips that explain what venture capitalists are looking for, and how to position your company if you are looking for a capital injection in the range of $1 million to $30 million.

At the other end of the global economic scale, more than one billion people in developing countries are not connected to the electrical grid, and rely on kerosene lamps and battery-powered torches, which have a much higher "cost of light" than conventional, grid-powered lighting. LED lights powered by solar panels eliminate the health and safety hazards of kerosene lamps, and can have a huge social impact in terms of business and education. Light becomes essentially free, once the hurdle of the initial purchase price is overcome. As described in our article page 38, companies such as Barefoot Power are building a substantial (and for-profit) business selling low-price, high-quality LED lights to the poor. In several years' time, the expectation is for this to become a multi-billion-dollar market that also significantly improves consumers' quality of life.

Solar-powered LED lights do not consume electricity, although there is certainly an energy-consumption budget associated with manufacturing many millions of such products. However, an interesting discussion has arisen concerning the future levels of energy consumption by lighting, as LED lighting becomes more and more prevalent. More efficient lighting should reduce energy consumption in the future–right? Well, yes, but what if the progressively lower cost of LED-based lighting means that people can install more and more lighting? The overall energy consumption may not fall much at all. But human productivity is also a factor. This somewhat contentious subject is discussed further in our Last Word column on page 76.

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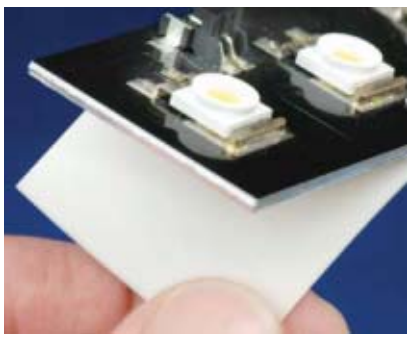

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China SSL
October 14-16, 2010
Shenzhen, China

LEDs 2010
October 25-27, 2010
San Diego, CA, United States

electronica 2010
November 9-12, 2010
Munich, Germany

LED Forum Moscow 2010
November 10-11, 2010
Moscow, Russia

ForumLED Europe
December 7-8, 2010
Lyon, France

The Arc Show 2011
January 12-13, 2011
Business Design Centre, London, UK

SPIE Photonics West
January 22-27, 2011
San Francisco, CA, United States

Strategies in Light 2011
February 23-25, 2011
Santa Clara, CA, United States

Strategies in Light China
May 10-12, 2011
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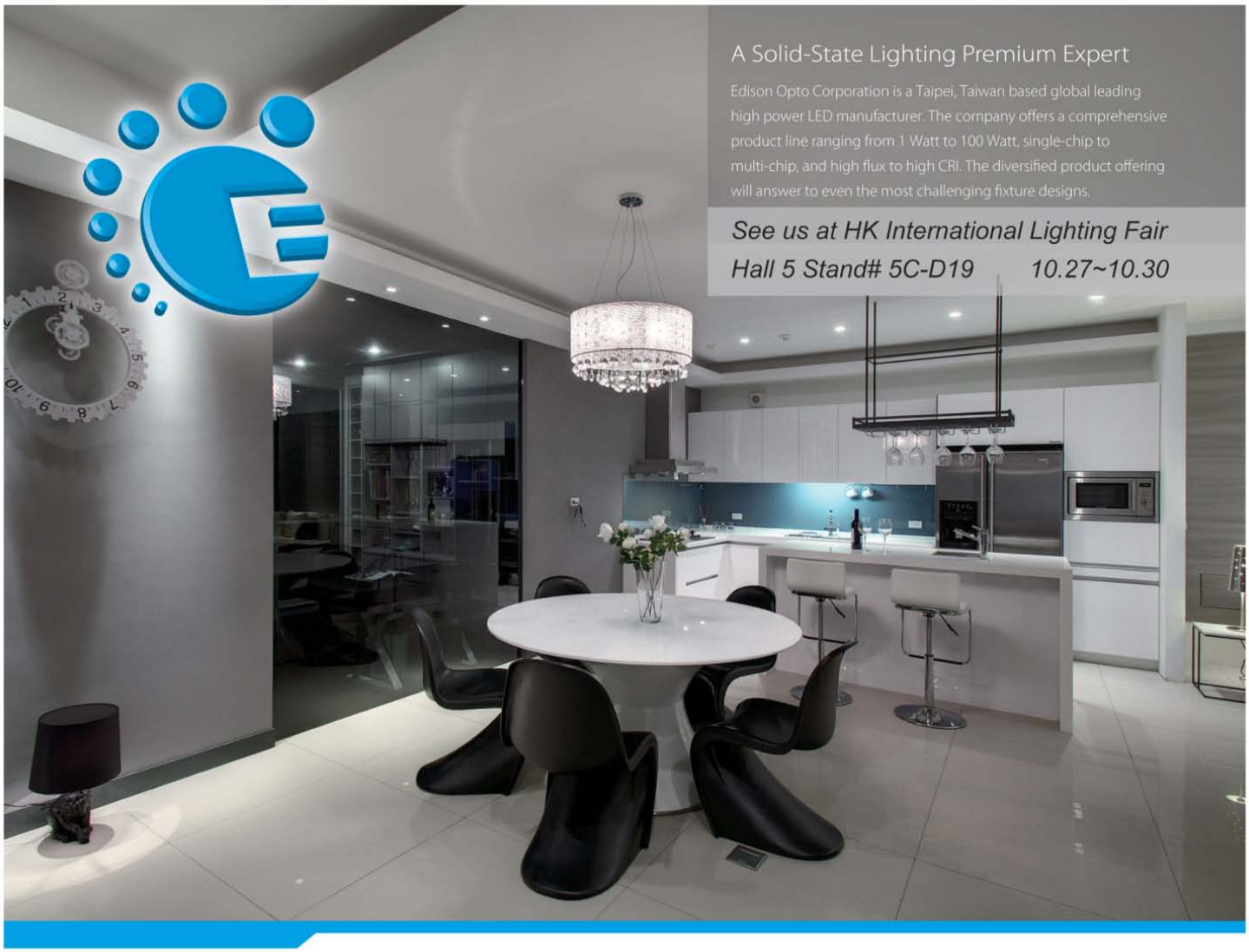

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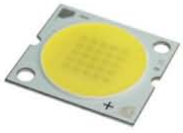
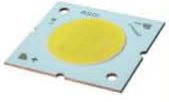
Pictures				
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Current(A)	0.7~1	0.7~1.2	1.0~1.5	1.5~2.2
Voltage(V_F)	6.4~6.7	12~12.8	15.5~16.5	21.2~22.6
Walt(W)	4~6	8~15	16~24	30~50
CCT(K)(Typ.)	5000~10000			
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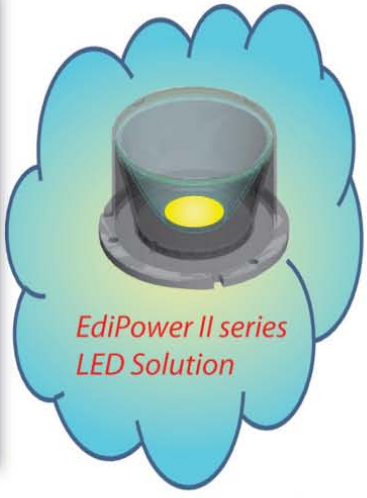

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news views

LED PRODUCTION

Luxeon shipments hit the billion-unit mark

Philips Lumileds shipped its billionth Luxeon LED in the second quarter of 2010. The company says that the high-power LED market—which was pioneered by Lumileds and is defined as comprising LEDs with 350 mA or higher drive current—is now a decade old. Even more impressive than the one-billion-unit mark is the fact that Lumileds shipped 750 million Luxeon LEDs in the past two years, driven by demand from the automotive, SSL, and consumer electronics markets.

"When we started, the idea that Lumileds could change the nature of lighting with power LEDs was greeted by many industry insiders with skepticism," said CEO Michael Holt. "Today, they and others have followed us as competitors into an industry that is driving energy-efficient lighting applications and new ways of lighting the places where we live, work, and play. This isn't just a milestone for the company but for the entire industry."

Lumileds continues to increase its LED production capacity, and recently placed a repeat order with Aixtron AG for multiple AIX 2800G4 HT systems. The MOCVD chip-growth systems will be shipped within the next 2-3 » page 10

The new Mercedes-Benz CLS coupe is the latest car to offer full-LED headlamps. A total of 71 LEDs not only provide an unmistakable appearance, says Daimler, but also a significantly enhanced view of the road compared with previous systems. In related news, Daimler AG has adopted Luxeon Rebel LEDs for use in the daytime running light (DRL) function on several vehicle models within its fleet, beginning in June 2010 with Mercedes-Benz E-Class models.

LAMPS

The Home Depot unveils LED lamp range

The Home Depot, the world's largest home-improvement retailer, is promoting its wide selection of LED lamps and says it now offers "the first affordable 40W-equivalent LED [lamp]"– an A19 model priced at $19.97. All the lamps are currently available on homedepot.com and will be in all US The Home Depot stores by the end of September.

"The Home Depot has stepped forward with the most cost-effective LED [lamps], employing the latest and most advanced LED technology available," said Craig Menear, executive VP for Merchandising. "Our partnerships with leading LED manufacturers, including Philips, Lighting Science Group (LSG) and Cree, have enabled us to » page 10

CHIP MANUFACTURING

Rubicon wins 6-inch sapphire supply contract

Positive financials are hardly news right now for suppliers to the LED industry, but Rubicon Technology's strong second-quarter performance deserves note because it was in part due to 6-in sapphire substrates. Moreover the company announced a $71 million supply agreement with an unnamed LED manufacturer for 6-in substrates.

The move from 4-in to 6-in wafers could significantly boost LED production capacity and reduce component prices. A 6-in wafer has more than double the surface area of a 4-in wafer, and can yield more than double the LED chips per wafer.

Rubicon stated that it has been supplying 6-in wafers to a number of companies developing 6-in production capabilities. The $71 million contract, however, will be for volume production as Rubicon will supply polished 6-in substrates from November 2010 until December 2011.

Raja Parvez, Rubicon's president and CEO, said, "While we have been supporting several LED » page 12

quarters and will be installed in Lumileds' production facility in San Jose, California.

Until high-current devices were introduced, LEDs generated only a few lumens when typically driven at 20 mA. In contrast, Lumileds recently introduced the Luxeon Rebel ES family that has an output of more than 300 lm at 1A. At lower drive currents, the efficacy is as high as 125 lm/W at 350 mA. ◄

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

FINANCIAL

Cree's annual LED product revenue reaches $790 m

Following a spectacular year of growth, LED maker Cree posted record revenue of $264.6 million for the quarter ended June 27, 2010. The company's LED revenue accounted for $240.12 million of the total revenue for the quarter, compared with $136.70 million in the same quarter last year – an increase of 76%.

For its fiscal year ended June 27, 2010, Cree's LED product revenue was $789.95 million. Its overall revenue of $867.3 million was 53% higher compared with the previous year, and its net income increased 402% to $152.3 million.

As well as seeing its LED downlights on sale in The Home Depot (page 9), Cree will supply LEDs for a major housing project in Singapore. Optiled Lighting International will deploy solid-state lighting retrofits in 400 of the 588 buildings that comprise the Jurong Town public housing estate (see www.ledsmagazine.com/news/7/8/2). Optiled will ultimately install 64,000 SSL luminaires that use Cree XLamp XR-E LEDs in what the company proclaims to be "the largest public LED lighting makeover that the Singaporean government has ever conducted."

Also, Cree is supplying LED lights to a home being constructed in Durham, NC by Habitat for Humanity. The house will be 100% lit with LEDs and this will deliver an annual energy saving of $250. The SSL products for the new Durham home is part of Cree's previously-announced pledge to provide $1.5 million in SSL products for Habitat homes over three years (see www.ledsmagazine.com/news/7/8/10). ◄

Home Depot from page 9

be the first in the market to offer affordable options for a wide array of fixture types for a consumer's home."

The company offers a proprietary brand of LED lamps under its EcoSmart name. The 40W-equivalent A19 lamp, offering 429 lm with a 50,000-hour expected lifetime, is manufactured by LSG (see www.ledsmagazine.com/press/22332). Whether 40W-equivalency can be claimed for an output of 429 lm is a matter of debate – see www.ledsmagazine.com/news/7/6/5.

As well as the LSG-made, EcoSmart-branded lamps, The Home Depot has several Philips-branded lamps, for example a 4-watt AmbientLED MR16 flood in cool white priced as $29.97.

Also under the EcoSmart brand is a 65W-equivalent LED downlight with 6-inch trim, which is priced at $49.95. The 10.5W downlight (pictured on page 9) is manufactured by Cree and is designed to be easily installed into most standard six-inch recessed housings for retrofits and new construction. It is dimmable to 5 percent using most off-the-shelf dimmers, says Cree (see www.ledsmagazine.com/news/7/8/19). ◄

FINANCIAL

SemiLEDs files for $172.5 million IPO in the US

Idaho-based LED maker SemiLEDs will seek to raise capital through an initial public offering (IPO) to both expand its manufacturing and reduce component costs. The company registered with the US Securities and Exchange Commission (SEC) to sell $172.5 million in shares. SemiLEDs hasn't set a target share price, but the filing indicates that the offering will be underwritten by Bank of America, Merrill Lynch, Barclays Capital, and Jefferies & Co. The stock will be

news+views

traded on the NASDAQ exchange using the symbol LEDS.

In the filing, the company specifically identifies solid-state lighting (SSL) as its target market, but notes that the upfront cost of SSL will gate the size of the market. One of the company's stated strategies is to "reduce cost through technology and manufacturing improvements," and it claims that its strengths include a vertical copper-alloy chip structure. The filing cites net revenue for the nine months ended May 31, 2010 as $24.275 million. ◄

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

ACQUISITIONS

Acuity acquires Renaissance Lighting and IP

Acuity Brands has acquired the remaining stock in Renaissance Lighting for an undisclosed cash payment, giving Acuity outright ownership of Renaissance's luminaire line and extensive intellectual property (IP) portfolio related to LED-based optical technology. A separate IP acquisition includes patents that had been exclusively licensed to Renaissance.

Acuity had previously invested $9.1 million in Renaissance and received a license to certain IP including the Constructive Occlusion optical system that is used in the Gotham (an Acuity Brand) Ecos downlight luminaire family. Now Acuity will have full access to Renaissance's SSL portfolio. Acuity said the deal would extend its "innovation capabilities in SSL and controls." ◄

MORE: www.ledsmagazine.com/news/7/7/21

OLEDS

OLED lighting market of $6.0 billion predicted by 2015

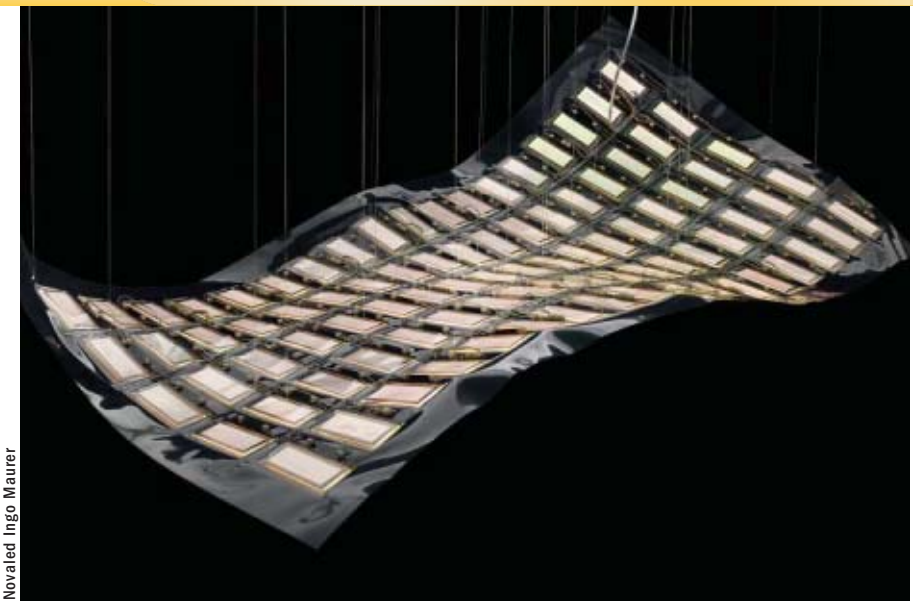
A market research report from NanoMarkets says that OLED lighting will generate $6.0 billion in revenue worldwide by 2015. The growth will be driven by the need for cost-efficient lighting in a number of different applications, including general illumination, architectural lighting, backlighting, vehicular lighting and signage.

Rubicon from page 9

customers in their development efforts on six-inch substrates, this is the first LED chip manufacturer to move into volume production on this size material. We are proud that our capabilities in large-diameter sapphire are helping the LED industry continue to evolve."

Rubicon reported that revenue rose to $15.8 million for the quarter ended June 30, 2010 – a 37% sequential gain. Parvez said, "Revenue from the sale of six-inch polished substrates more than doubled sequentially as our customers continue to make progress on their development efforts." ◄

MORE: www.ledsmagazine.com/news/7/8/6



Novaled Ingo Maurer

The report (see www.ledsmagazine.com/press/24979) says that most of the firms offering or planning to supply OLED lighting are focusing on general illumination and/or architectural lighting, which together will account for just over $4.0 billion by 2015. The report discusses the types of OLED lighting products that will be needed as effective substitutes for today's incandescent and fluorescent bulbs and tubes, and the price points that these new OLED lighting products will fetch. However, there are also other applications for OLED lighting with considerable potential. For example, vehicular lighting is expected to amount to $750 million by 2015.

The report also includes two different scenarios for OLED backlighting; one in which OLED prove themselves to be an effective substitute to today's electroluminescent lighting, and a second in which OLED technology reaches a level of development where it can provide an effective backlighting technology for LCD displays. Under this second scenario, where OLEDs would be used rather than LEDs, NanoMarkets believes that the OLED backlighting market could be as high as $1.4 billion.

Novaled provides OLED lighting guide

Novaled, a leading OLED manufacturer, has written a substantial guide to OLED lighting for designers, luminaire makers and others involved in the lighting business. The company says that the unique technical features of OLEDs are expected to result in a fundamental change not only in lighting applications but also in the structure of the lighting industry itself. OLEDs can deliver unique design features: they are ultra-thin and potentially flexible light sources that can be transparent or mirror-like in the off state.

The OLED lighting guide describes key

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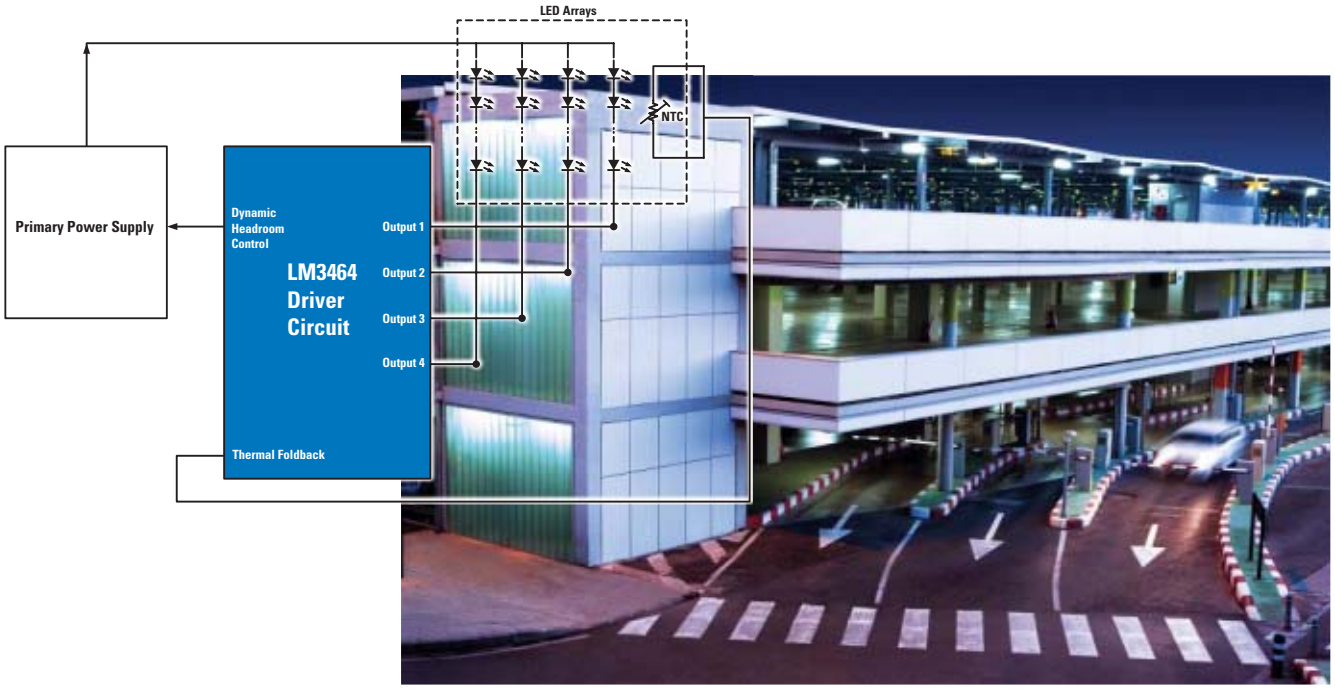

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OLED lighting attributes, unique application aspects and design potential. It provides a view on the industrial development of OLED lighting technology including market drivers and players and an application roadmap. It also suggests the need for a rethink on lighting, away from point sources and away from thinking of lighting only for space illumination. It provides an overview on a range of actual lighting and design products based on OLED lighting technology, including Novaled case studies such as the Ingo Maurer "Flying Future" lamp (pictured on page 14). ◄

The Climate Group

Philips is now a partner in the 1000-Village Solar LED lighting program, which is bringing solar-powered, LED-based lighting to 1000 rural villages in China, India and Africa. The five-year project launched in August 2009 as a joint initiative of The Climate Group and Chinese film star Jet Li's One Foundation. Philips has already donated solar-powered LED roadway lighting with adaptive controls for installation in the Guiyang City region of China. ◄

MORE: www.ledsmagazine.com/news/7/8/5

PLANAR LIGHTING

Epistar invests in planar LED lighting specialist Oree

Oree Inc., the Israel-based developer of LED planar illumination technology, has secured an investment from Epistar, Taiwan's largest manufacturer of LED chips. The solid-state light source developed by Oree is thin and flat – about the size and shape of a credit card – and is ideally-suited for general lighting applications, decorative and architectural lighting, as well as backlighting for LCD panels. Oree says that it is currently working with selected customers in Asia and Europe, and will be in high-volume production by early next year. Epistar has been manufacturing chips for Oree since 2007. The chip maker has partnered with a number of companies with novel and promising technologies, for example having made an investment in Lynk Labs in October last year. ◄

MORE: www.ledsmagazine.com/news/7/8/13

LED MANUFACTURING

TSMC invests in LED manufacturing line

TSMC, the giant Taiwan-based silicon IC manufacturing foundry, has passed a Board of Directors resolution to assign US$101.6 million for an LED production line. As we reported in March 2010, TSMC has already started to construct its first LED fab in Hsinchu Science Park, Taiwan. TSMC is the leading contract IC fabricator and believes it can transfer its manufacturing expertise to LEDs. "LED lighting is a promising industry, and we will make full use of TSMC's technology leadership and manufacturing excellence in semiconductors to develop and integrate LED technology, process, and packaging and testing," said Rick Tsai, TSMC President of New Businesses. ◄

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sapphire [substrates] and other raw materials" but planned to increase its chip production capacity. It currently has over 50 MOCVD systems, and estimates the number will increase to approximately 80 systems by year end. MOCVD systems capable of growing on 6-inch wafers are also planned for installation by year end, said Lextar, which is a subsidiary of AU Optronics Corp (AUO), the LCD panel maker. The company is building new production bases in Chunan, Taiwan and Suzhou, China. ◄

MORE: www.ledsmagazine.com/news/7/8/26

LICENSING

Luminus licenses PhlatLight LED platform to Epistar

A licensing agreement will allow Epistar to manufacture LEDs based on Luminus' PhlatLight LED technology platform.

Alexei Erchak, CTO of Luminus, said that the technology will enable Epistar to improve its LED performance, while Luminus will continue to focus on manufacturing big-chip LEDs for applications where LED arrays don't provide enough brightness. "We are pleased to broaden our partnership with Luminus as their strong IP portfolio includes LED patents that enable unmatched levels of brightness and reliability," said M.J. Jou, president of Epistar. Earlier this year, Luminus licensed its LED technology to Forepi. ◄

MORE: www.ledsmagazine.com/news/7/8/16

HOSPITALITY

Everlight LEDs light up Burger King restaurant

Burger King has equipped its first energy-efficient restaurant, opened in early June in Waghäusel, Germany, with LED lighting from Everlight Electronics Co., Ltd. As part of a scheme making extensive use of renewable energy sources, the energy consumption by lighting has been reduced by more

than 55% annually compared to traditional lighting. The parking area is illuminated by six 60W SL-Dolphin street lights in neutral white (5000K) with a luminous flux of 6000 lm. The asymmetric wide-view angle ensures high uniformity at pole heights of 6-8m.

Inside, the restaurant's guest area features red pendant lights in an Italian design that contain Everlight's 7.5W A-Lamp replacement LED lamp. ◄

MORE: www.ledsmagazine.com/news/7/9/1

SOFTWARE

National Semiconductor launches Webench design tool

Computer-aided-engineering tools have long boosted the productivity of electrical engineers designing circuits, and now engineers working on SSL luminaires can use the National Semiconductor Webench LED Architect to jumpstart their projects. The tool allows engineers to quickly evaluate LEDs, LED drivers, heat sinks, and passive components for SSL designs. It provides engineers with immediate comparison data in key areas such as power consumption, lighting performance, and cost. Webench LED Architect allows engineers to compare a broad range of components. The tool can analyze 350 different LEDs from 12 manufacturers. The software includes 30 heat sink options, 35 LED drivers, and 21,000 passive components that can be mixed and matched in SSL designs. Once an engineer creates a SSL design optimized to the application requirements, the Webench tools can generate a complete project report including schematics, a bill of materials, and performance characteristics. ◄

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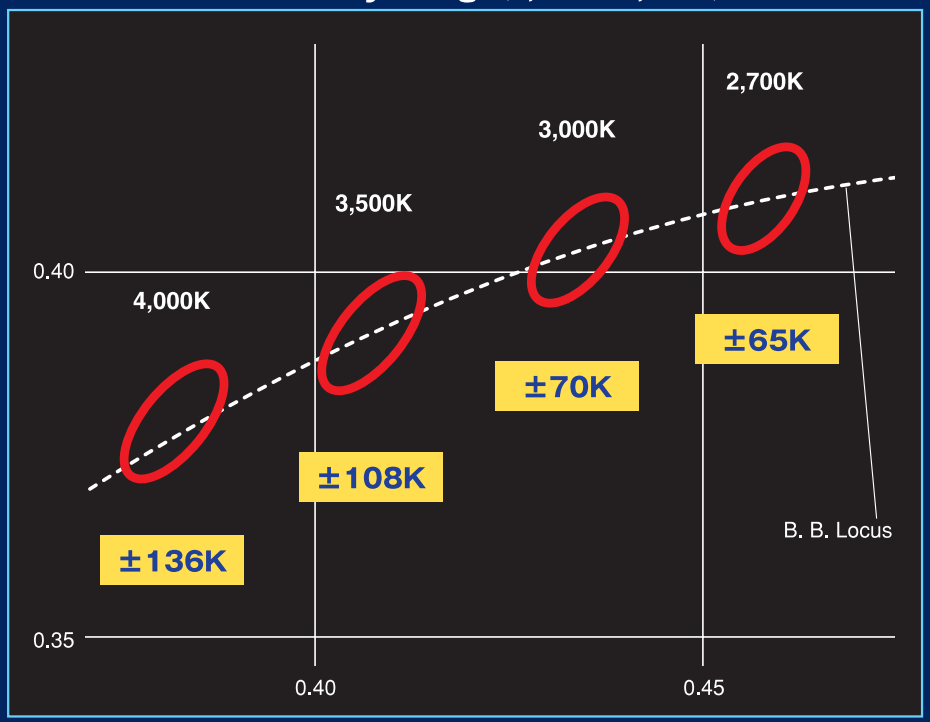

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Indoor Lighting

Digital Lumens lights Maines warehouse

The Maines Paper & Food Service 400,000-sq.ft. warehouse in Conklin, NY, has been fitted with an Intelligent Lighting System supplied by Digital Lumens. This has reduced lighting energy usage to 13% of former levels, due both to the more efficient LED technology and to the integrated controls that can dim or extinguish lights in unoccupied areas. The warehouse is a 24-hour operation, but at any given time many aisles are empty. The SSL installation replaced high-pressure-sodium (HPS) high-bay lights, and resulted in higher light levels, with 20 foot candles to the floor. Maines considered other energy-efficient options, but the ability to dim or extinguish LEDs was a key decision point. Also, high-efficiency fluorescents would have added to the refrigeration and lighting costs. The Digital Lumens system relies on Zigbee wireless technology to link the luminaires in a mesh network. In this case, several Zigbee gateways connect back to the Maines computer network via Ethernet, allowing control by any networked PC.

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

D-LED and Future showcase jewelry

Under- and in-cabinet LED lighting fixtures that are one-tenth the height of comparable non-LED luminaires have helped transform Royalty Jewelry's 430-sq.ft. boutique in Tel Aviv's Ramat Aviv Mall. The Source Linear System fixtures

were created by D-LED Illumination Technologies in collaboration with Future Lighting Solutions. The ultra-slim (49 mm wide x 24 mm high) fixtures contain Luxeon Rebel LEDs and have reduced electricity costs by $1,300 per month.

MORE: www.ledsmagazine.com/casestudies/25848

MSi delivers savings for Las Vegas retailer

RC Willey, a furniture retailer based in Summerlin, NV, recently replaced all 4500 of the 90W halogen spotlight lamps in its 50,000 sq.ft. Las Vegas showroom with 10W iPAR LED lamps from MSi Lighting. Within hours of installation store employees had noticed a drop in the showroom's temperature. Management was able to raise the air conditioner thermostat setting by four degrees, resulting in an annual saving of $90,000 in cooling costs alone. Also, the typical 90W halogen light burning 12 hours a day will need to be replaced approximately every four months, compared with up to 12 years for the 10W iPAR. This translates into a further $21,000 annual cost saving. Over the 12-year lifespan of the LED lights, the estimated total saving will be "somewhere in the neighborhood of $3.4 million" in this one showroom alone.

MORE: www.ledsmagazine.com/casestudies/25713

Dialight LED high-bays cut the mustard

At the G.S. Dunn quality control and inspection facility in Hamilton (Ontario, Canada), light quality and accuracy is a primary concern to ensure the company's dry mustard products meet its stringent standards. As part of a strategic plan to optimise visibility and reduce energy consumption, the company replaced 18 of its 450W metal-halide units with Dialight's high-efficiency DuroSite LED High Bay fixtures and gained not only superior color rendering, but also significant cost and energy savings.

MORE: www.ledsmagazine.com/casestudies/25711

Kompak opens Europe's first all-LED plant

A consumer-products packaging plant owned and operated by Kompak and located in Etten Leur, The Netherlands has been lit exclusively with LEDs. All interior and exterior lighting fixtures were developed and installed by Dutch company LedNed and feature Cree XLamp LEDs. A lighting system, Lightline, provides uniform illumination over all horizontal and vertical surfaces. The warehouse ceilings are nearly 14m high. Lightline features motion detection, daylight correction and other custom options to increase light availability in spaces where more light is required.

MORE: www.ledsmagazine.com/casestudies/25389

San Diego State installs Lithonia LEDs

San Diego State University has installed more than 80 RTLED luminaires from Lithonia Lighting for ambient lighting, as well as 30 DOM8 LED luminaires for downlighting. The 215-person-lecture-hall project represents the University's plans to reduce energy and costs and achieve sustainability. "The first day we turned on the lights 100 percent, they were so bright it was astounding. We were all in awe," said architect Jeffrey Herr.

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

funding + programs

DOE publishes updated plan for SSL manufacturing R&D

The US Department of Energy (DOE) has published the 2010 edition of the Solid-State Lighting (SSL) Manufacturing R&D Roadmap, which complements the Multi-Year Program Plan that guides the DOE's Core and Product Development R&D programs (see www.ssl.energy.gov). The manufacturing roadmap's primary goal is to guide the manufacturing R&D program and help direct funding solicitations. It also provides guidance for equipment and mate rial suppliers, based on industry consensus on the expected evolution of SSL manufacturing. The overall goal is to reduce risk, improve quality, increase yields, and reduce costs.

The 2010 roadmap differs from the 2009 version mainly in the addition of specific manufacturing R&D task priorities (seven different categories for LEDs and four for OLEDs) and also includes updated forecasts of costs as the DOE's understanding advances.

Among the manufacturing priorities listed for luminaire/module manufacturing is a 2x increase in manufacturing throughput by 2015, and a reduction in book-to-build time from 10 weeks in 2010 to 5 weeks in 2015. Also, the OEM lamp price is targeted to drop from $113/klm in 2010 to $28/klm in 2015. Industry stakeholders strongly supported bringing advanced manufacturing concepts to LED luminaire manufacturing, says the roadmap, and R&D projects that could be funded under this task should help manufacturers focus on reducing costs and waste in their processes.

The driver is currently estimated to be approximately 20% of the LED luminaire cost and offers a logical target for potential cost reductions. One route is driver integration, and there is a target for 2015 of 50% reduction in luminaire cost over non-integrated driver approaches. Also, the target for driver cost is a reduction from $22/klm in 2010 to $4/klm in 2015.

For test and inspection equipment, the roadmap calls for a 2x increase in throughput. One specific area of interest is the high-speed monitoring of color quality and color consistency in order to improve the back-end quality and reduce overall costs.

Various targets are also set for tools for epitaxial growth, and for wafer processing equipment. One target is to reduce the epitaxy growth cost by a factor of 3, while for wafer processing the roadmap calls for significant increases in wafer throughput, yield and productivity.

Packaging accounts for approximately 65% of the packaged LED cost, or approximately 25% of the entire luminaire cost today. The roadmap calls for a 50% reduction every 2-3 years in assembly cost, the cost of packaging, and the end cost of the package. The seventh and final LED manufacturing priority deals with phosphors.

For OLEDs, the manufacturing R&D priority tasks are OLED deposition and patterning equipment; integrated manufacturing and quality control; OLED materials manufacturing; and back-end panel fabrication.

• For two weeks in early October, the BrightSpots LED Forum online panel discussion will enable industry professionals to partake in an active discussion exploring the key issues surrounding HB-LEDs, from design to manufacturing (see www.ledsmagazine.com/news/7/8/25). ◄

DOE plans consumer-education initiative on energy-saving lighting

The US Department of Energy (DOE) used its SSL Market Introduction Workshop in Philadelphia in July to preview a new consumer-education campaign to promote "green" lighting options. The DOE will partner with GE, Philips, Cree and Osram Sylvania, as well as major retailers including The Home Depot, Costco Wholesale and Grainger, to promote LED-based lighting and other energy-saving lighting options. The DOE is planning the initiative to coincide with upcoming changes in light-bulb regulation. The Energy Independence and Security Act of 2007 will begin a phase-out of incandescent bulbs in 2012, starting with the 100W lamp and then continuing with lower-wattage bulbs on a progressive basis over a two-year period.

The DOE believes that, without an effective consumer-education process, the new performance levels being put in place could cause considerable confusion. Most people are used to selecting light bulbs on the basis of their wattage, which is not an accurate indication of light output for efficient technologies like SSL. Therefore, DOE plans to work with the lighting industry to educate the public on the use of lumens as a measure of light output. The new campaign will also seek to define other benefits of new lighting technologies, including for instance the long lifetime promised by SSL. The DOE will formally launch the initiative this fall, and more details will emerge in the coming months.

A comment on the LEDs Magazine website (see www.ledsmagazine.com/news/7/7/18) applauds the initiative, saying there is an "appalling lack of awareness" about the light-bulb ban and its implications. "The DOE and industry leaders have to educate loudly, effectively and relentlessly," adds the comment, "but more voices are needed to get consumers up to speed on this." ◄

funding + programs

GE websites focus on lighting legislation

GE has launched two new websites that together with its existing Environmental Information Center site will educate consumers and businesses on the transition to energy-saving lighting options such as LED-based lighting. The new sites are the Understanding 2012 Lighting Legislation site (www.gelighting.com/2012) focused at consumers and on the move away from incandescent lighting, and the Legislation Product Replacement (LPR) Tool site (www.gelighting.com/legislation) that helps businesses check the legal status of luminaires.

The LPR site is focused at the lighting-specification community, including engineers, lighting designers and architects. Such professionals can use the tool to see if any recent legislation will have an impact on the use of specific products such as luminaires.

The new sites supply information about both federal legislation and regulations in the US, and state regulations. For example, State of California laws will go into effect a year prior to federal laws in many cases.

The consumer-focused site provides a detailed explanation of federal legislation that will phase out 100W incandescent bulbs in 2012 followed by 75W and 60W bulbs in 2013 and 2014, respectively. The site also offers energy-saving calculators that consumers can use to select more-efficient lighting. ◄

MORE: www.ledsmagazine.com/news/7/8/9

Street lighting consortium expands

The DOE's Municipal Solid-State Street Lighting Consortium will host its first Annual Meeting on September 29, 2010 in Huntington Beach, California. The meeting will immediately follow the IES Street and Area Lighting Conference to enable attendees to learn more about Consortium efforts to develop outdoor lighting guidelines, to launch regional education workshops, to initiate the first Consortium demonstrations, and to establish interchange between related efforts and organizations.

In July, the DOE hosted a webcast entitled "Evaluating LED Street Lighting Solutions," featuring consortium speakers. Materials can be found on the DOE SSL website at www.ssl.energy.gov. During the webcast, Consortium Director Edward Smalley provided an overview of the organization's membership, current activities, and future plans as it builds a network of information on LED street lighting.

Tod Rosinbum from the City of Portland, Oregon discussed how two ongoing demonstrations will influence city planning going forward. John Walter from National Grid described potential benefits of and concerns about the technology, and outlined the utility's role in helping customers evaluate and implement LED street lighting projects. Finally, Amy Olay from the City of San Jose, California shared her municipality's perspective as it converts to LED streetlights that utilize adaptive lighting controls.

And the market said, "Let there be LED."

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Venturing into LEDs: An overview of venture capital and its investment in lighting

The LED and solid-state lighting industry is a growing segment of focus for the venture-capital community. **DENNIS COSTELLO** of Braemar Energy Ventures explains the reasons for this level of interest and describes what makes a particular company in the sector attractive as an investment target for venture capitalists.

It is becoming harder and harder not to notice the amount of venture-capital dollars that are flowing into the coffers of lighting companies in the US. Over the last couple years, venture-capital-backed financings have been announced in Bridgelux, Luminus Devices, Superbulbs, Fulham, Terralux, Nuventix, Digital Lumens, Albeo, QD Vision, LedEngin, and Renaissance Lighting, just to name a few. Are these just aberrations or has the venture-capital community made a serious and long-term commitment to lighting? What are venture-capital firms looking for when they invest in lighting companies? Most importantly, how can your company best position itself to secure venture-capital dollars to fuel expansion?

The last decade

The venture-capital industry has been going through many changes in the last decade. Each year, it seems to become more difficult for venture-capital funds to produce the returns that have made the industry famous. The average rate of return of venture funds has declined in the last 10 years and many are facing serious losses. That has led to a decline in the amount of funds flowing into the sector, especially when compared to the boom that characterized the period of 1997-2001 (fueled by an unprecedented number of internet and telecommunications investments).

The cleantech (or energy-tech) sector has been one of the few new bright spots in venture capital. Cleantech investing has seen steady growth. Ironically, cleantech has now surpassed the venture-capital investments in information technology and biotech. As of the first half of 2010, there were $2.18 billion in cleantech, $736 million dollars invested compared to in information technologies and $2.10 billion invested in biotechnology (source: PricewaterhouseCoopers/National Venture Capital Association MoneyTree Report). This is quite a startling statistic in light of the central role historically played in venture capital by information technology and biotechnology.

Energy efficiency & generation

In sum, there seems little doubt that cleantech is now a key focus of venture capital. Since venture-capital funds generally are structured to have 10-year lives (and most venture-capital companies take three to four years to fully invest each fund), it is unlikely that the trend will be reversed any time soon. The next logical question is: "Where has all this new money gone?" The answer, in a word, is solar. Just take a look at investments in the second quarter of the year, the most recent period tracked by the Cleantech Group (www.cleantech.com). The leading sector in the quarter by amount invested was solar: $811 million in 26 deals.

Energy efficiency (of which lighting is an important part) has taken a back seat to energy generation technologies as the venture-backed cleantech sector has grown up. However, that trend is also changing. In 2009 and 2010 to date, the venture-capital community has rediscovered energy efficiency. Energy-efficiency investments are now the fastest growing segment of the cleantech sector, especially if batteries and energy storage are included in the energy-efficiency category.

Energy efficiency is a broad term that can include a huge variety of activities. Some venture capitalists have been delving into energy efficiency in transportation as highlighted by the recent initial public offerings of A123 (the battery company) and Tesla

DENNIS COSTELLO *is a managing partner with Braemar Energy Ventures (www.braemarenergy.com), a leading energy venture-capital firm whose investments include Nuventix, Fulham, Luminus Devices, Laser Light Engines and Lumenergi.*

Motors, the electric-vehicle company. Tesla is the first new automobile company to go public since Ford Motor Company in 1956. Other firms have focused on energy-efficient buildings, from heating and cooling, to better insulation, to software controls to new materials for windows and walls. A growing number of firms are seeing the potential of lighting and especially LED lighting in buildings.

"The most successful new LED companies will have good technologists, good entrepreneurs, and seasoned lighting professionals."

Favorable factors for LEDs

So the LED industry is in the enviable position of being a growing segment of focus of the venture-capital community. It is helpful to better understand why that is the case and therefore what makes a particular company in the sector attractive as an investment target. It is not an exaggeration to say that venture capitalists are looking for outsized returns in relatively short periods of time. Every venture capitalist may have a different view of what situations produce these types of returns. However, some factors are generally agreed as favorable.

First, an industry going through huge changes can produce big opportunities. There is no doubt that LEDs are creating a seismic shift in the staid lighting market. The investment by Philips through its acquisitions of Color Kinetics and then Genlyte was an early beacon of the changes to come. The success and stellar value of Cree in the public market is another indicator. The complete transition in focus of the annual Lightfair tradeshow -- from no LEDs a few years ago to mostly LEDs in the latest show -- is yet another small indicator of that seismic shift. Potential new large Asian entrants into lighting also add impetus to this market shift.

Second, regulatory and environmental pressures are building which will force massive changes in the lighting industry. Most of us are familiar with the regulatory bans on incandescent lights that are already happening. Japan and Cuba banned incandescent in 2007. Brazil and Venezuela passed similar legislation in 2005. In the next couple years, China, the European Union, Australia, the US and Argentina will join that group.

Third, the economic viability of LED lighting to the end-user, independent of government intervention, is changing rapidly. The costs of LEDs are dropping as major companies ramp production and improve lumen output. Compared to incandescent and halogen lighting alternatives, LEDs can already show payback periods in the range of 1.5-3.5 years. LEDs are getting closer to being competitive with compact florescent lamps, and most believe they will become competitive with metal halide and linear florescent in the coming years.

Finally, LEDs are a semiconductor device and have shown the same characteristics as other solid-state digital devices. This is familiar territory for many VCs who have been involved in the semiconductor industry for decades. Predictable lowering of costs matched with increased efficiency of output has been a winning formula for many industries as they transition from analog to digital. Lighting is on the same path.

What venture capitalists are seeking

It may be a good idea to invest in an industry that is undergoing fundamental changes but that alone does not guarantee success. All venture capitalists are ultimately forced to place a limited number of bets on specific companies. Lots of money has been lost by backing the wrong companies in hot markets with good fundamentals.

The most important characteristics that venture capitalists seek are the same in lighting as in most other sectors. They include the strength and experience of the management team; the size of the market opportunity that is being targeted; the innovation or technology that allows entry to the targeted market; how that innovation can be protected from competitors; proof points (including revenue); that customers understand and appreciate the unique innovations being offered; the likelihood that the company will be successful enough to be acquired or go public; and the capital (especially equity capital) that will be needed to get the company to reach that successful exit.

Much has been written in the general business literature about what makes companies successful and how to present your business in a manner that will appeal to a venture capitalist. Rather than repeat the clichés about what attracts venture capital, let's focus on a few of the factors that are specific to LED lighting companies.

Tip 1: Match your business opportunity with the right capital provider

If your company is still in the product development or early revenue stage (less than $3.0-5.0 million in annual sales), and you are seeking a relatively modest amount of equity capital (i.e., you want to sell stock in your private company, not just take out a loan), your best bet is probably individual investors or so-called angel investors. Angel investors typically invest their own capital and often work through clubs. In fact there is a national Angel Capital Association, which is a good starting point to find a group in your area. Angel financing rounds are usually smaller than $1.5-2.0 million and often include several individuals sharing the risk.

If your capital needs are between $1 million and $30 million, you are in the range of most venture-capital financings. Some venture funds like to invest alone but most prefer a syndicate of like-minded funds. Venture capitalists will fund start-up companies, companies in product development, and companies with revenue. Typically, the company is privately-owned and

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not making profits consistently. If you own a well-established company that is cash-flow positive and has significant scale, you are probably best-suited for larger private-equity firms, rather than venture capitalists.

Tip 2: Assure your business opportunity warrants the amount of capital needed

To be taken seriously by a venture capitalist, it is important that you can justify rapid revenue growth within a few years of the investment and that the company has the potential to grow to a substantial size. The venture fund is looking to make well over three to five times its total investment and the fund usually owns a minority percentage in the company (less than 50%). That math dictates that the selling price of the investment has to be substantial. The more money needed to get to an exit, the larger the exit value must be.

It should also be noted that venture capitalists take business projections a bit more seriously than many entrepreneurs. One of the standard jokes in the venture community is that the projections must pass the "snicker test." In other words, the revenue, margins and earnings have to be credible and achievable. One good question to ask yourself is: "Have other companies in my market ever grown at the pace we are projecting?" If not, you may get a snicker when you present it to a VC.

> "It takes persistence, good preparation and sometimes many months of effort to raise venture money."

Another good check is to see if the size and growth of your revenue is reasonable in light of the market your product is addressing. If your projection requires market shares that only multinational companies have achieved, you are undermining your credibility. Alternatively, it does not suffice to argue that lighting is a market in the billions of dollars and you are grabbing less than one percent of that market share. Venture funds spend considerable time trying to understand which slice of the market your product can truly address. If you have not done that same analysis in advance, the probability of getting funding is diminished.

Tip 3: Assemble a great and balanced staff to execute your plans

Luckily, for entrepreneurs and the overall industry, there are many views of what makes a good company within the venture-capital community. Some venture capitalists will not consider an investment unless the technology is so novel that it can change an entire industry. Others focus more on the quality of the key management and the development of sales channels. The deals with the highest likelihood of success demonstrate strength in both of these dimensions.

At the very core, LEDs represent a new, innovative, unfamiliar technology that must somehow get integrated into a very well-established physical and business infrastructure. A better technology will not assure success in lighting. In fact, there are many examples of adequate technologies beating out superior technologies because of how they were introduced (and by whom) into the existing lighting markets.

The most successful new LED companies will have: (1) good technologists who are experts with the product; (2) good entrepreneurs who are willing to challenge old established ways of doing business; and (3) seasoned lighting professionals who understand manufacturing and sales channels. That balance should be mirrored in the Board of Directors as well as the senior management team.

Tip 4: Find powerful and cost-effective channels to your customers

The most successful new companies we have seen in the LED space have taken unique technology and leveraged partners to get it to the market. The lighting market is not like the internet market. A nice website and some money for advertising and trade

LINKS

Bridgelux raises $50 million (Jan 2010) www.ledsmagazine.com/news/7/1/11

Braemar Energy Ventures invests in lighting component supplier Fulham (May 2009) www.ledsmagazine.com/press/18723

LedEngin closes Series D funding round led by NGP (Jul 2010) www.ledsmagazine.com/news/7/7/15

Luminus closes $19 million funding round led by current investors (Feb 2010) www.ledsmagazine.com/news/7/2/22

Lumenergi secures $12.7 million in venture funding (Aug 2010) www.ledsmagazine.com/press/26018

Nuventix secures an additional $8 million in funding (Apr 2009) www.ledsmagazine.com/news/6/4/11

QD Vision receives $3 million from DTE Energy Ventures (Jan 2010) www.ledsmagazine.com/press/20931

Renaissance Lighting closes $10 million financing round (Sept 2007) www.ledsmagazine.com/news/4/9/32

Acuity acquires Renaissance Lighting and intellectual property (Jul 2010) www.ledsmagazine.com/news/7/7/21

TerraLUX receives $5.6 million venture capital investment (Mar 2010) www.ledsmagazine.com/press/21511

shows is not enough. Sales of LED technologies into distribution or OEMs are difficult, slow and costly. A good fundable company will have a strong strategy on how it will go to its market. A key element of that strategy usually involves partners. One way to impress a venture capitalist is to have this strategy completed in advance with well-known partners. It is a strong validation of the value of your company if someone else is interested in bringing it to market.

Tip 5: Understand the role of intellectual property in your business

It is hard to find an industry with such a morass of patents, licenses and cross-licensing as in LED. To make matters worse, we have all seen patents used as both defensive and offensive strategies in this space. A couple of issues around intellectual property are on every venture capitalist's mind when they see an LED company. First, does the company have the freedom to execute its business plan without violating patents they do not own or license? Second, does the company own intellectual property that keeps others from invading its markets after some commercial success has been demonstrated? Finally, does the intellectual property owned by the company have value to others in the future? If a company has prepared in advance for these questions, and used experts to frame their strategy around intellectual property, it will have a leg up in fund raising.

Summing it up

It is never easy to raise capital from the venture-capital community. Only a very small percentage of those seeking funding are successful with any given firm. It takes persistence, good preparation and a sometimes many months of effort to raise venture money. It is a selling process, with much in common with selling your LED products. Remember that each venture capitalist is different and will have a different view on the same facts. Keep in mind that no venture capitalist is going to understand your business at the same level as you. Your job is to both educate the venture community in an honest manner (the truth will come out sometime so best to start out that way) and to listen to their reactions and views. Many have had experience with a very broad sample of businesses and have seen what works and what does not work. And of course, the best venture capitalist to work with is one who understands your business and can provide you with guidance, help and counsel rather than just money.

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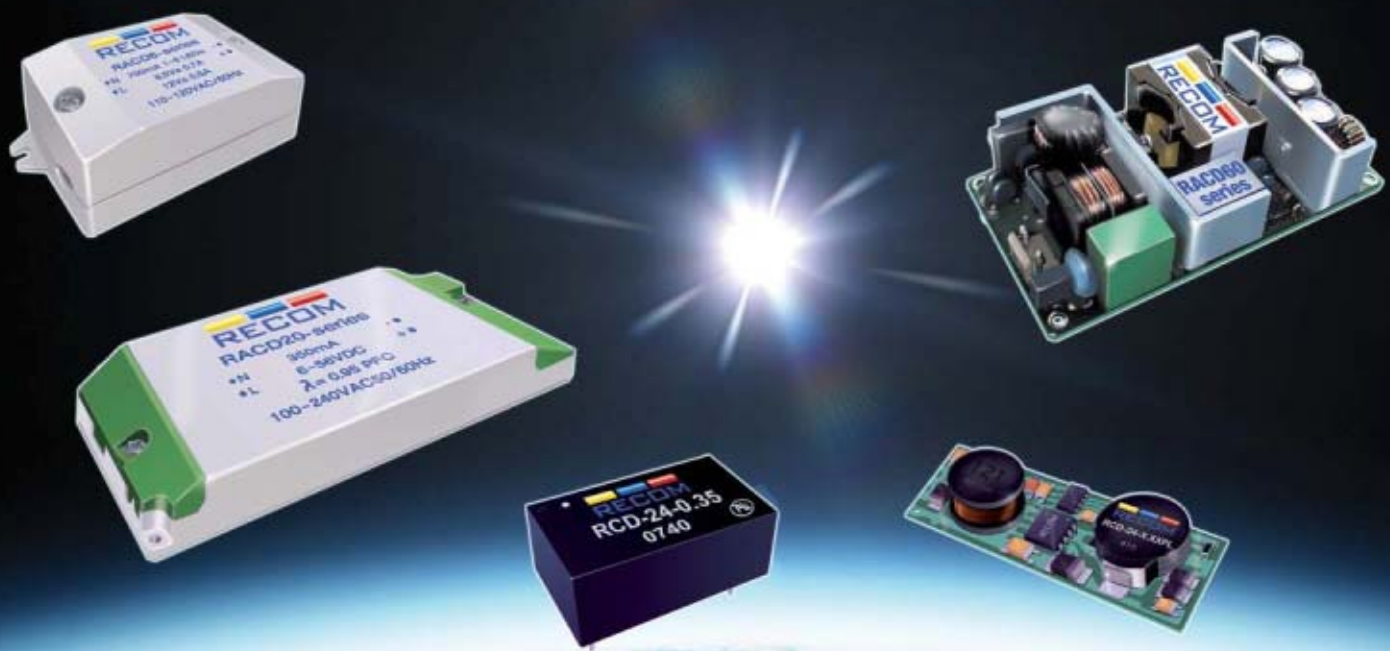

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LED driver lifetime and reliability hold the key to success in LED lighting projects

Product lifetime and reliability are two very different but related concepts. Understanding the issues relating to both parameters is a critical aspect of designing a product that will perform as expected in the field, explain **GEORGE MAO** and **MARSHALL MILES.**

Due to growing environmental concerns, the world is now replacing billions of conventional incandescent light fixtures. While a large percentage are currently moving to compact fluorescent lamps (CFLs), concerns over the mercury content of CFLs, as well as the potential for even greater energy savings, are causing more and more users to move to LED lamps. The newest LED lights consume approximately 80% less energy than incandescent lamps and contain no toxic materials.

After electronics-rich CFLs began to replace incandescent bulbs, consumers began seeing the products' early failures all too frequently. The introduction of electronics into general-purpose lighting creates new failure modes that must be understood.

While LED lighting has the potential to provide significantly longer life and better reliability, the question is whether or not the necessary power electronics are up to the task. While many poorly-designed products have tarnished the reputation of LED lighting, the light engine of properly-designed LED lighting systems should last for up to 50,000 hours. However, unless the power electronics driving this light engine are designed for correspondingly long life and high reliability, this advantage will not be realized.

Lifetime and reliability

It is important to understand that product lifetime and product reliability are two very different, although not unrelated, concepts. Unfortunately, as they are both often expressed in hours, they are frequently confused.

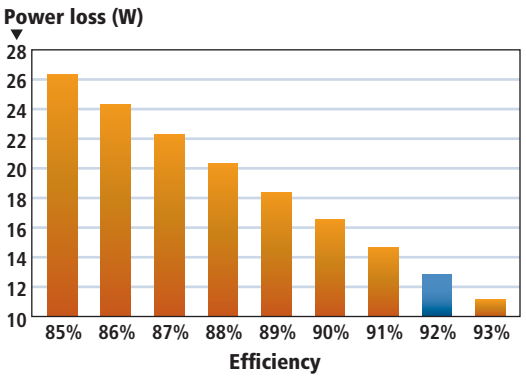

FIG. 1. Power loss vs. efficiency for 150W driver.

Lifetime refers to the length of time a user can expect a single product to work properly before a known wear-out mechanism renders the product unfit for use.

Reliability deals with the random failure rate of a population of products. It may be expressed as a failure rate such as failures in time (FIT), or as the inverse, mean time between failure (MTBF).

A lifetime of 50,000 hours implies that one would expect any given product to last up to 50,000 hours before failing. An MTBF of 50,000 hours implies that for a population of 1000 units, one could expect to see a random failure every 50 hours. Both concepts are important to understand and manage for a successful implementation of LED lighting.

Lifetime and capacitors

Estimating the life of any product is primarily a matter of identifying all known wear-out mechanisms and then identifying the shortest-lived component in the system that will render the product inoperable. For most electronics power supplies, including LED drivers, that component will be an electrolytic capacitor. The electrolyte in the capacitor will vent over time as a function of the operating temperature of the capacitor. That temperature is a function of case temperature as well as the internal heating caused by ripple current in the capacitor. While it may vary somewhat for different manufacturers or part numbers, the typical equation for the life of an electrolytic capacitor is shown in Equation 1.

EQ. 1

$$L_x = k \cdot L_o \cdot 2^{\frac{T_s - T_a}{10}}$$

L_x = lifetime

k = factor determined by capacitor's RMS ripple current and operating voltage; can be either a value or a function

L_0 = lifetime value tested in standard condition provided in the datasheet

T_s = rated case temperature

T_a = operating case temperature.

With knowledge of Equation 1, it becomes fairly straightforward to optimize the designs. The first priority is to select a high-quality, long-life capacitor. Second, the designer should strive to reduce the capacitor's RMS ripple current and operating voltage relative to its rating. This involves both minimizing the ripple current and voltage while also selecting a capacitor with suffi-

GEORGE MAO *and* MARSHALL MILES *are with Inventronics (Hangzhou) Co., Ltd. Web: www.inventronics-co.com.*

cient design margin. Over-specifying the capacitor will result in a larger and more costly product than necessary. Under-specifying can significantly compromise the life of the product.

Temperature and efficiency

The last and most effective design priority is to decrease the case temperature of the capacitor. The temperature of the capacitor will be a function of the ambient operating environment of the driver, the ability of the driver to conduct or convect heat into the surrounding environment, and the amount of power dissipated in the driver itself. For a given case design and application, the primary contributor to temperature will be the power dissipated in the driver, which is directly a function of the efficiency of the driver. In other words, high efficiency and a low-thermal-resistance design can significantly improve the lifetime.

Efficiency has a much greater impact than many people realize. For example, moving from 95% efficiency to 85% efficiency is not a 10% change in the amount of power dissipated. Rather, it increases the heat dissipated by a factor of 3.3X.

Inventronics is devoting great efforts to improving the efficiency of LED drivers. Take for example the popular EUC-150S (150W constant-current output) series. As shown in Figure 1, when the 220VAC full-load efficiency is 92%, the loss is only 13W. As the output power becomes higher, only 1% efficiency difference can cause a large change in power loss.

Since products of different designs can have significantly different efficiencies, the temperature inside the enclosure can be greatly different. As shown in Equation 1, a reduction in temperature of 10°C doubles the lifetime. Even assuming the thermal design is the same, which means the thermal resistance from the bulk capacitors to air is the same, drivers with different efficiencies will result in different Ta (operating case temperature) and therefore yield very different lifetimes. Figure 2 shows efficiency versus lifetime, still using a 150W product as an example at 45°C ambient.

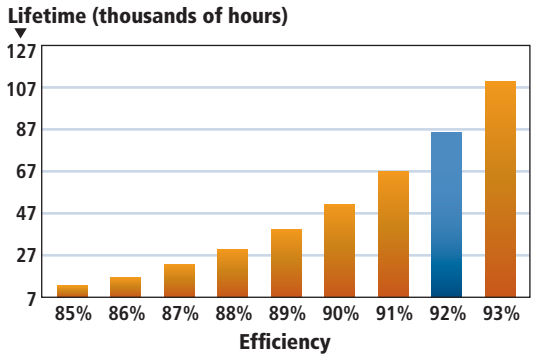

FIG. 2. Lifetime vs. efficiency for a 150W LED driver.

Without good heat conduction and/or convection, the limited power loss can generate high temperatures inside the driver, even if a driver maintains high efficiency. Utilizing a good thermally-conductive potting compound inside, as well as a robust aluminum case with ample surface area, can greatly reduce the thermal resistance from device to ambient. This particular driver achieves 87,000 hours lifetime operating in a 45°C ambient. This is better than most LED light engines and will contribute greatly to the profitability of LED lighting projects.

Reliability, MTBF and FIT

Reliability deals with the failure rate of a population of products operating within their rated conditions and within their operational life. A common way of expressing the reliability of a product is mean time between failure (MTBF). Even though reliability and lifetime are both often expressed in terms of hours, the concepts are still quite different and that difference should be understood. Equation 2 expresses the very simple concept of MTBF. It is the total operational time in hours of a population of products divided by the number of failures.

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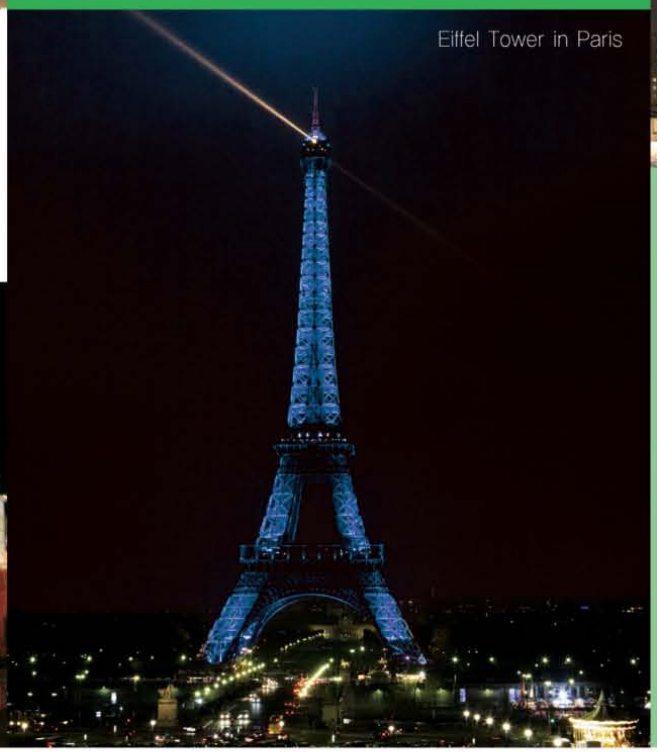

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$$MTBF = \frac{Total\ Time}{Failures} \quad \text{EQ. 2}$$

As an example, a population of 1000 products operating around the clock will accrue 24,000 hours of operation per day. If this population of products operates for one month and produces 4 failures, then the MTBF would be (1000 units x 24 hours/day x 30 days)/ 4 failures = 180,000 hours.

To provide another example, if a product is found to have an MTBF of 300,000 hours then a population of 1000 such products would likely exhibit one failure about every 300 hours on average. Similarly, a population of 10,000 such products would exhibit one failure about every 30 hours on average.

To be clear, if a product has an MTBF of 300,000 hours, this does NOT mean that any given product would be expected to last for 300,000 hours. The MTBF only holds for the operational life of the product i.e. before any known wear-out mechanisms could be expected to occur.

Perhaps a better way to understand reliability is to look at it in terms of failure rate. Equation 3 shows that failure rate is simply the inverse of MTBF. However, because the resulting number can be quite small, it is common to multiply this number by 10^9 and talk in terms of failures in 10^9 hours, also known as failures in time (FIT).

$$Failure\ Rate = \frac{1}{MTBF} \quad \text{EQ. 3}$$

When determining the life of a product, it is only necessary to identify the shortest-lived component and calculate its life. However, when determining the reliability of a product, it is necessary to understand the failure rate of every component that can cause the product to fail and look at the combined failure rate.

Plenty of time has been spent on research of estimating reliability of electronic equipment. The most common of these methods is MIL-HDBK-217, a military specification which is considered to be the standard reliability-prediction method and is the method used by Inventronics. Another fairly common method is the Telecordia SR-332 reliability prediction model. Typically the military result is more conservative and produces a lower number than the commercial Telecordia method. Either of these will be referred to as calculated reliability numbers, as opposed to demonstrated reliability which is actually measuring the failure rate of a population of products. While comparing two products using the same methodology proves to be a very valid comparison, comparing the reliability of products using different methods is virtually meaningless.

Designing for reliability

The challenge is to produce the most reliable product possible given certain size and cost constraints. There are several key considerations when designing for reliability. First

is the topology selection for the power stage design. A semiconductor's reliability is usually dependant on the operating junction temperature. Soft switching topologies like ZCS flyback and LLC half bridge can be utilized to minimize the switching loss of power switches, thus improving the thermal condition of both the semiconductors and the whole driver.

Second, the selection of high-quality components, yielding adequate component-stress margins, should be considered. For instance, 20% operating voltage margin for electrolytic caps and 10% voltage margin for semiconductors are always a must for a reliable design. Third, protection circuits can help products survive from various kinds of abnormal conditions including over current, over/under voltage, over heating and short circuit. Also, surge-suppression circuits should be used to prevent the driver from being damaged by lightning.

The fourth point brings us back to the issue of efficiency and thermal design as discussed previously. Heat has a direct and significant impact on the reliability of semiconductors like MOSFETs, ICs and opto-couplers.

One final important issue regarding reliability is understanding and eliminating infant mortality – the initial early failures of a product coming off the production line. As mentioned earlier, the concept of product reliability is valid only during the useful life of the product. It no longer applies when the product reaches any of several possible wear-out mechanisms. It should also be noted that it only applies after the initial phase of infant mortality.

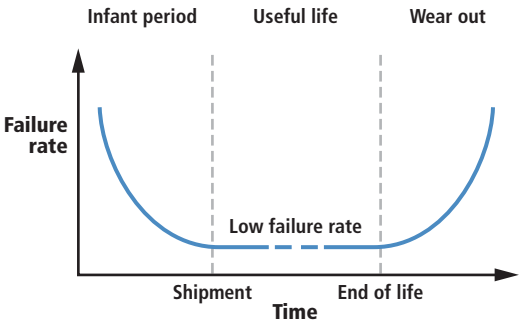


FIG. 3. The bathtub curve of failure rate over time.

Figure 3 shows the well-known "bathtub" curve of failure rate versus time. Most electronic products will demonstrate an initial higher failure rate, which is referred to as infant mortality. The product then enters its useful life – the flat bottom portion of the curve. Finally, failure rates begin to rise as the product experiences a wear-out mechanism.

The challenge of the manufacturer is to ensure that those products destined for premature failure never leave the factory. In order to screen out these failures, Inventronics utilizes a robust dual-burn-in process on 100% of its products. Every product is put through a burn-in process prior to potting for 1 to 2 hours. Then, after final assembly, all products are powered up under heavy load and high temperature and run for anywhere from 4 to 12 hours. Products are then subject to a final suite of functional tests. The objective here is to eliminate early field failures that not only reduce the profitability of LED lighting installations but damage the perception of the lighting manufacturer.

Summary

Understanding the issues relating to both lifetime and reliability are critical to designing a product that will perform as expected in the field. This is especially true of projects such as LED lighting where payback is measured in years, where long warranties are a business necessity and where a reduction of maintenance costs forms a significant portion of the return on investment.

While there are many factors which must be considered, we have seen the importance of efficiency and its use as a key metric in evaluating LED drivers. While LED drivers can be designed to meet the requirements of today's lighting projects, it takes a great deal of care and analysis to ensure that these objectives are met.

LED lighting provides long-term value for the poor

Off-grid LED lighting provides clear benefits for users in developing countries, and can also be built into a profitable business for committed suppliers, explain **STEWART CRAINE**, **HARRY ANDREWS** and **SAM ANDREWS**.

In Tanzania earlier this year, several students died in a dormitory fire at a school. The cause? Kerosene lamps. It is estimated that thousands of people, often women and children, die as a result of fires started by kerosene lamps in houses and other living quarters, while tens of thousands suffer non-fatal burns for the same reason. At the same time, it is estimated that tens of billions of dollars are spent burning this fuel for light, or on disposable batteries for torches, which have a cost per kWh 100 times higher than grid power, perhaps $5.00/kWh.

Given this high cost, both financial and otherwise, spent on tiny units of energy by 1.5 billion people worldwide in dozens of developing countries, it is not surprising that the smallest LED lights have a much faster payback period than those used in developed countries.

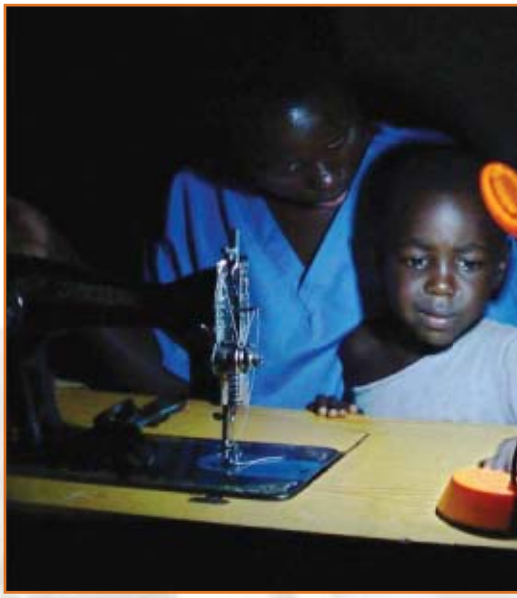
By investing in such lamps, and often in solar panels to charge them, the money spent on kerosene is not burned into smoke each year, but is instead captured in long-lasting expandable energy assets, creating almost a new way of saving and building wealth. However, installation of an LED lamp and solar panel in a house also means the retirement of the symbol of the last 100 years–the kerosene lamp–and the potential of a bright future ahead. These non-financial social impacts and benefits are important and real, but rarely factor into a potential investor's spreadsheet.

Growing an off-grid lighting industry

Barefoot Power was incorporated in 2005, with a stated aim to bring clean lighting to one million people by 2010, and to fulfill a profitable business plan. Many adventures later, we are closing in on that goal, with a variety of systems from 0.5W to 15W or higher finding great reception in markets from Guatemala to Papua New Guinea, from India to Sierra Leone.

We also recognize the shared experiences of the early trailblazers like Light Up The World, Mighty Light and the Lumina Project, and more recent projects such as Lighting Africa [see Links]. These form a foundation of knowledge to which we add our experiences in an open-source fashion, to grow the off-grid lighting sector into a multi-billion-dollar market.

Micro-energy and LED lighting is cur-

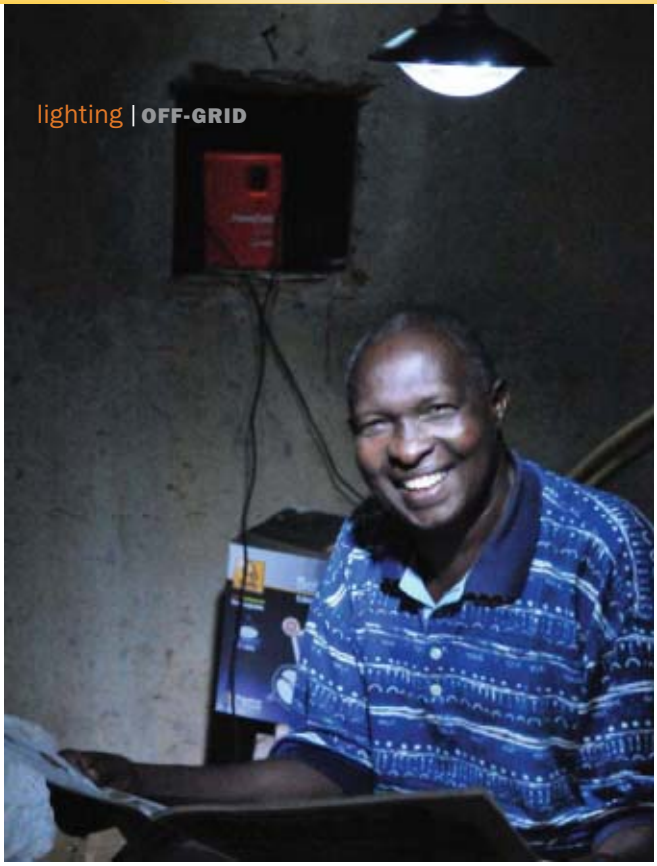


STEWART CRAINE *(Director),* HARRY ANDREWS *(Director) and* SAM ANDREWS *(General Manager, China) are with Barefoot Power (www.barefootpower.com), a social entrepreneurial business that designs and manufactures LED lighting and other technology products that have the potential to reduce poverty in developing countries.*

rently a sub-billion-dollar market, putting it where mobile phones were 20 years ago, and where microfinance was 15 years ago. However, most early movers are seeing such strong demand that supply gaps are very common, as investors fail to keep up with the pace of change in these "high risk" markets.

There are two sets of suppliers in the market. The first group consists of companies with strongly-branded, high-quality, high-cost products that sell 0.5-100W renewable or rechargeable lamps (both LED and fluorescent) to off-grid households. Examples include Grameen Shakti, Selco and Sundaya; smaller specialists such as Barefoot, D.light and GreenLight Planet; and large corporations such as Shell, BP, Philips, Osram and Schneider Electric. Adding up publicly-available data for these and 50-100 other suppliers indicates a total annual market of $100-300 million, with end-consumer loans or financing required for perhaps 50% of units sold.

The second group consists of weakly-branded companies with low-to-medium-quality, low-cost products. Field studies indicate at least 50% of all 250 million households that lack electricity, plus a similar number that are on-grid and suffering power outages, spend at least $5/year on low-cost, short-life LED torches. These are often AC-rechargeable and have generally forgettable "brands," although sometimes



the brand has quite strong consumer recognition within China. This China-supplier category could represent expenditure of as much as $1 billion per year on as many as 200 million lights. Such products are already showing impressive market penetration and market dominance by aligning with consumers' cashflow preferences. They generate some benefits, such as improved household safety, but are lacking in others such as the wealth-creation benefits of longer-lasting products.

Asian LED quality improvements

However, the market is on the move. Barefoot Power started improving quality levels in Chinese factories for LED lamps and solar panels back in 2006, using typical sources of startup capital. In five years, no donor support has ever been secured for this work, as the focus remains on the capacity-building challenges for the distributors and entrepreneurs, rather than supply challenges.

Barefoot and the Lumina Project collaborated in 2006 to produce some understanding of variations in LED quality from 25 suppliers in south-east Asia at that time, as shown in Figure 1. The general result was that a surprising number of 5mm LEDs had high efficiency of 40-60 lm/W, but there was also a tail of quite terrible products, which could easily be spotted in the market and removed from being a sourcing option.

Lifetime data was not available until later, but Figure 2 shows how Barefoot has seen LED life improvement in the last 4 years: LED prices have not changed much, but degradation is now far better than it was, and efficiencies are improving. It is interesting to note, however, that even under-driven 5mm LEDs quickly degraded but then stabilized at 50-60% of initial output. While the official "failure" of a LED is defined as a reduction to 70% of initial levels, households regularly use battery-powered LED lamps on high, medium and low settings, so lamps with LEDs at 50-60% of initial output would definitely still have been in use.

LED lamps are typically 3-5 times brighter than a kerosene lamp, so even with 2006 degradation levels, improved lighting would result. To account for possible initial degradation and an improvement in LED quality, Barefoot desk-lamp products had replaceable circuit boards, to allow for easy upgrade. This has not generally been utilized, as other design features also added have prompted the first buyers to buy a completely new lamp 1-3 years after purchasing their first lamp.

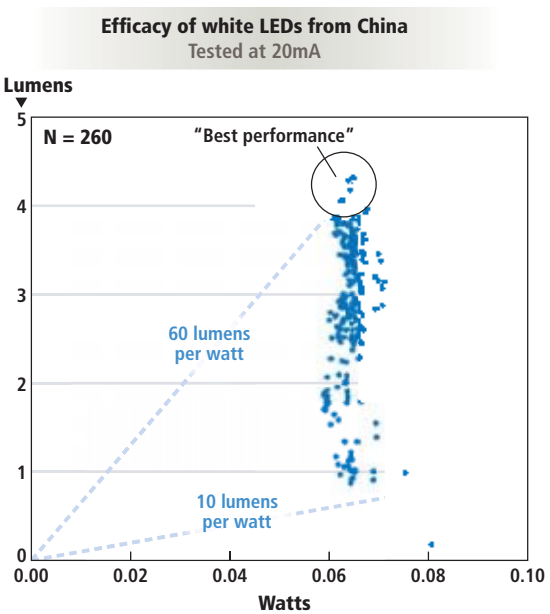


FIG. 1. Efficacy of white LEDs available from China. Source: E Mills, The Lumina Project Research Note #1, May 2007 (http://light.lbl.gov/pubs/rn/lumina-rn1.pdf)

Production challenges

Maintaining production quality levels is a major and constant challenge in China (and probably in any country). Some challenges are unique – 90% of factory workforces are lost each year as factory workers disappear home at Chinese New Year, then work at a different factory, often in another town, after the holiday. So in February, there is no production, and in March a massive training effort has to be undertaken with new staff. The assumption of China's limitless workforce is also being challenged as the government provides better opportunities inland, causing real shortages in coastal areas.

Growing in the dark

However, these issues are not unique to our business or our industry. With appropriate margins, and staff placed in China, our production and global sales unit is reaching good scale that can generate profits in a similar manner to tens of thousands of other Western companies based in China who source and supply for EU/USA/Australasia-based customers. The Barefoot team, backed by a growing group of angel and social investors, is pushing the supply of a wide range of high quality product to market.

Demand is soaring after Barefoot Power won several product awards at this year's international off-grid lighting conference organized by the World Bank's Lighting Africa project (see www.ledsmagazine.com/press/23046). The products won three of the four first prizes and were placed sec-

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FIG. 3. Firefly 1.5W LED lamps on sale in Rio Azul village, Quiche. Guatemala. Right: happy customers.

ond in the other category. The 5W PowaPack four-lamp kit was awarded first place in the both the Top Performance and Room Lighting categories, while the 1.5W Firefly desk lamp was the winner in the Best Value category for products that cost under $40, and also came second in the Task Lighting category.

Given that we had been asking for a 1-2 page off-grid lighting specification since 2006, and were "flying blind" until the Haiti earthquake forced the issue to resolution, we believe our products and design philosophy have contributed notably towards these standards coming into being, and that they are appropriate to the market they serve.

To ensure the containers are sold, the bulk of our team are deployed in countries such as Uganda, Kenya and India, as well as China and Papua New Guinea, to offer free "software" with the hardware that creates market pull. This "software" includes training sessions for entrepreneurs, business development assistance for importers and distributors, access to trade finance from our investor network, and customized ERP software. Some of this has been open-source released as an industry contribution, with three publications released on the Renewable Energy and Energy Efficiency Partnership (REEEP: www.reeep.org) website.

In our core 4-6 countries, we "learn by doing" by operating our own subsidiaries that carry out importing and distribution, which also gains us additional margins and proves up our business model as profitable. However, importantly, our core markets help us build up experience that we share with 20-40 other partners worldwide in other countries.

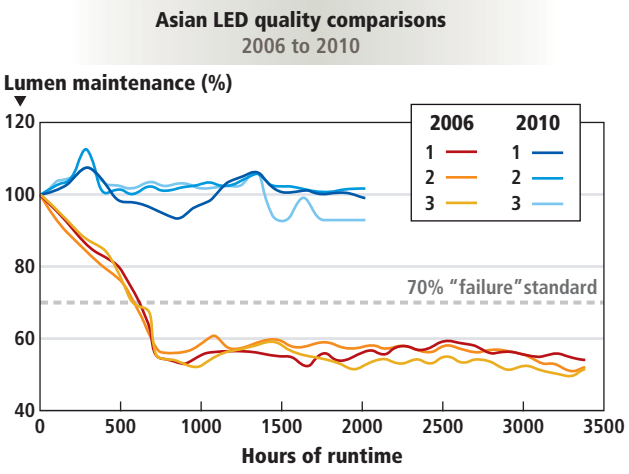

FIG. 2. Lumen depreciation results from Barefoot Power internal quality-control test reports on 5mm white LEDs, August 2010.

The hours are long and the pay has been very poor, but tens of thousands of smiles keep us going. Soon, after 10 years of trailblazing by others and ourselves, investors will "get it" and the fun will begin. Each month, we reach tens of thousands of new households with 0.5-15W products, train dozens of micro-energy entrepreneurs, and the range continues to expand with innovative new technologies and designs creating more wealth for the end customer.

Even the lowest-cost competing products from China are improving in quality these days. As the industry grows 100-300% per year, we look forward to a multi-billion-dollar micro-energy industry within 2-3 years that will start to deliver on its potential, taking shape and defining the players involved, and gaining respect and support from investors. Tens of millions of end customers will gain even more benefits from safe, efficient, clean lighting, and other micro-energy solutions.

LINKS

Lighting Africa helps developers of off-grid lighting systems www.ledsmagazine.com/features/5/4/12

LEDs offer alternative to polluting, fuel-based lighting www.ledsmagazine.com/features/2/6/1

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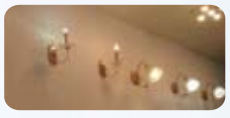

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lighting | OUTDOOR

SSL luminaires must deliver reliable beam patterns in outdoor applications

Luminaires for outdoor SSL applications such as street lights must deliver increasingly precise beam patterns to minimize light pollution and maximize efficiency by directing light to the appropriate area, says **MAURY WRIGHT**.

LED-based lighting is quickly gaining market share in outdoor-lighting applications including street lights, and area lights in shopping plazas and parking lots. At the same time, environmental activists are raising concerns about light pollution. The directionality of LEDs should be a good match with the goal of directing light to the proper place such as a roadway and not allowing light to trespass upon homes along a road. But designing an SSL luminaire to deliver correct beam patterns is a formidable task that LED makers, optical specialists, and luminaire manufacturers are all striving to solve.

LEDs are gaining popularity in outdoor lighting for a few simple reasons. SSL luminaires are more energy efficient and have a longer life than legacy technologies such as high-pressure sodium (HPS). That advantage translates to energy and maintenance savings for municipalities. But the SSL makers are being challenged by those concerned about light pollution to also offer better light control.

Most LEDs generate a beam angle of around 120° – a relatively narrow beam in the lighting world. Paul Scheidt, product marketing manager at Cree said, "It's been one of the fundamental advantages of LED technologies in [street lighting], the fact that LEDs are directional and it's fairly easy to control exactly where the light going."

But Scheidt notes that street lighting is still a tough challenge. He cites the fairly common problem of creating an elliptical pattern on the roadway. The problem is providing the same level of illumination 100 feet away from the fixture that you do directly under it. Scheidt asks, "How do you throw that much light in an efficient way and not create too much glare in the process?"

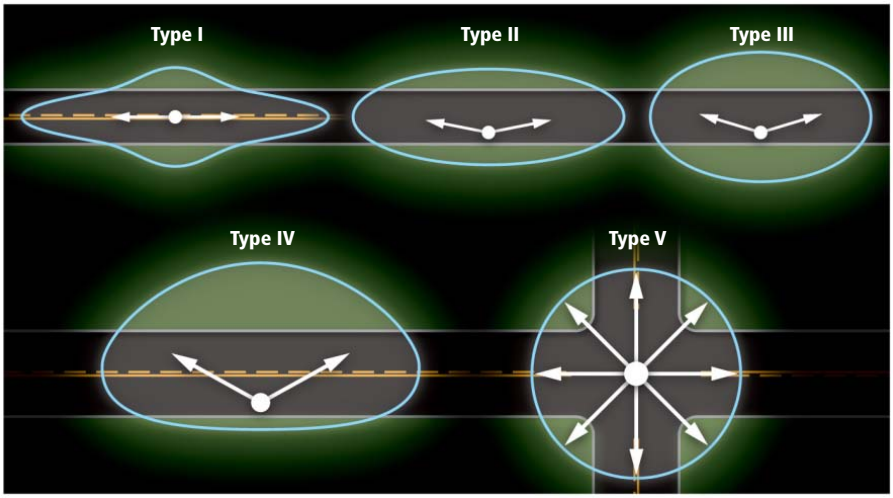

FIG. 1. The IESNA has defined five basic beam pattern types for roadway usage.

Indeed the task at hand is designing products that meet beam pattern specifications that have been set in North America by the Illuminating Engineering Society of North America (IESNA) and by similar bodies in other parts of the world.

There are five basic types of IESNA beam patterns (see Fig. 1.) that are used in street-light applications. The Type 1 and Type 5 patterns are generally considered quite simple to implement. But Types II, III, and IV are far more useful in street-light applications and more difficult to implement. For example, a Type IV pattern requires long throws and the luminaire must minimize light that hits the ground behind the fixture location.

Approaches to beam patterns

The approach to beam pattern must match the characteristics of the luminaire design in terms of the chosen LED light source. The bulk of street light luminaires today use 2-D arrays of individual LEDs mounted in a planar fashion that in aggregate deliver the required lumen output. Such luminaires may have as few as 20 to more than 100 individual LEDs.

It is also possible to use large-chip LEDs or arrays, such as those supplied by Luminus or Bridgelux. A street light based on such a product might have as few as 1 to as many as 10 individual light elements.

Back to beam angle, luminaire designers can mount LEDs at an angle to direct the light in the intended direction and there are certainly some such designs on the market. But that approach has more potential for glare issues. Designs can also use what is called a Total Internal Reflection (TIR) optical lens on each lighting element, which are designed to control light direction.

Cooper Lighting director of marketing

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

and product management Tim Hill said, "Each individual LED has an individual optic, like a small contact lens in a way, which bends the light into the target zone." In a street light, different TIR designs are used on different emitters in the array to in aggregate deliver the desired pattern.

Luminaire designers can also turn to reflectors to control and channel the light in the appropriate direction. Indeed it's a tried and true method. Luminus Devices director of systems and application engineering Don McDaniel said, "Stand in any parking lot and look up in a shoebox and what do you see -- a light bulb with a reflector and a piece of glass over it. It works."

Today the individual LEDs with a TIR approach appears most popular. Kenny Perez, a company principal at Nate Mullen Visual Concepts is working with several municipalities in the San Diego area on LED street-light upgrades and is active in the San Diego Street Light working group (www.ledsmagazine.com/features/7/7/7). According to Perez, the four luminaire designs gaining traction in trials around the country are BetaLED's LEDway (Fig. 3), GE's Evolve, the Leotek CG1, and the LED Roadway Lighting Satellite.

The BetaLED and Leotek products rely on individual LEDs mounted in a single plane parallel to the plane of the road, along with TIRs to control the light. The LED Roadway Satellite luminaires split the LEDs into left and right planes that are also angled slightly. The GE Evolve is quite different in that it combines an array of individual LEDs with concentric circular reflectors.

FIG 2. LLC TD Focus has supplied 200 luminaires based on the Osram Golden Dragon Oval Plus LED (shown inset) that are installed in Kemerovo, Siberia.

TIR optics can gate a design

The problem with the TIR approach is that designing the optics is very complex and expensive and can hamper smaller organizations trying to enter the SSL market. BetaLED and Cooper consider their TIRs a value-added feature of their luminaires and have branded the lenses NanoOptic and AccuLED respectively. But these are relatively big organizations with the financial backing needed to develop the TIRs and pay for the heavy upfront cost associated with injection molding.

There are other ways for an upstart luminaire maker to enter the market. For example, Osram Opto Semiconductor has developed the Golden Dragon Oval Plus LED that is specifically designed for street and other outdoor lights. The LED is packaged by Osram behind an oval lens that helps generate some popular beam patterns.

Osram product marketing manager Marc Dyble said, "It's designed to help our customers go to market faster. They don't have to incur the cost or time to design a new optic or find a way to utilize an existing optic."

Dyble isn't sure the major street-light luminaire makers that have TIRs designed will buy the product, but notes it has already found success with smaller manufacturers. In July, Osram announced (www.ledsmagazine.com/news/7/8/1) that the city of Kemerovo, Siberia had installed 200 Oval-Plus-based LED street lights manufactured by LLC TD Focus (Fig. 2). Each luminaire integrates 90 of the LEDs.

According to Dyble, the LED creates an "inherent Type 1 distribution." But he claims that luminaires can also be designed to produce Type II, III, and IV patterns based on the LEDs. Dyble stated,

Why not reflectors?

Of course there's inevitably a question as to whether the TIR approach is the best or if that was simply the only way early luminaire players could get products with good beam patterns to market. Bridgelux VP of Marketing Jason Posselt said, "That's somewhat just an issue of what products have been available to the market." Posselt points out that mainly luminaire designers have had access to 1W-3W emitters for several years and naturally turned to large arrays of those LEDs for a high-light-output application such as a street light.

Since street lights are a high-light-output application, it would seem larger light sources might be a good match for the application. Fewer larger light sources, however, requires a move to a more reflector-centric approach. Whether it's a large single PhlatLight emitter from Luminus or a packaged array from Bridgelux or another vendor, TIRs are simply not feasible as a way to shape the light. The TIRs would have to be sufficiently large that the injection molding manufacturing process wouldn't yield reliable results.

Cree's Scheidt, Bridgelux's Posselt, and Luminus' McDaniel all agree that a TIR isn't a good choice for a larger light source. But they differ in opinion about whether a reflector approach might work just fine.

Scheidt said, "You can't control all of the light with a reflector." Scheidt points out

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that street lights go through a very stringent qualification process and believes that TIR-based designs are the only way to satisfy the efficiency and light-control requirements of many municipalities.

Large LEDs or arrays could reduce cost

Still, up-front cost is extremely important in LED street light deployments, because it takes years to pay back the investment through energy and maintenance savings. The proponents of larger light sources believe that the approach will ultimately yield lower cost luminaires and possibly superior light.

Posselt said, "If you build a street light that uses somewhere between 1 and maybe 10 arrays instead of 100 emitters, you've got fewer placement steps, you have fewer optics that you have to buy, and you don't have all of those manufacturing steps you have to take to put together a system."

The optics in such a case might be primarily a reflector or a reflector combined with some type of tertiary lens.

FIG 3. The LEDway street light features a NanoOptic TIR over each emitter. Photo courtesy of BetaLED.

Bridgelux is working to develop partners that can help create an ecosystem for the required optical components, noting that the TIR crowd has had several years to develop their optics technology. For now, Bridgelux only has customers in the prototype stage with street light designs. But Posselt claims that one such company believes it can save 30% using arrays as a source.

Luminus, meanwhile, actually demonstrated a prototype luminaire at Lightfair built by Almeco that relied on a single CSM-360 PhlatLight LED (www.ledsmagazine.com/news/7/6/3). The CSM-360 is 36 times larger than a typical 1W LED. Almeco is a materials specialist that won't build production luminaires but has reflector expertise. About the prototype, Luminus' McDaniel said, "The goal was to have no direct illumination. It was absolutely glare free." Now the company is looking for partners to go beyond the prototype stage.

Are TIR designs pleasing to the eye?

Bridgelux' Posselt is also quick to point out that the TIR approach with many individual emitters is not necessarily appealing to the eye. He said, "People don't like the bug-eye effect. They don't like seeing multiple points of light."

Of course it's almost impossible to judge how people perceive the quality of a light because if you call someone's attention to an issue like multiple lights or glare, then they notice the problem. Perez, the San Diego lighting consultant relates a story about driving through an LED trial site with his wife in the car. He then asked her about the glare and she hadn't noticed. Of course Perez did notice and said, "I'm a lighting geek and I'm always looking up."

FIG 4. Everbrite is conducting a test of its PSL125 reflector-based luminaire in parking-garage applications.

There is at least one reflector-based design that's being trialed in a parking garage application. Everbrite demonstrated the PSL125 luminaire at Lightfair and took a different approach to meeting the required beam patterns. The luminaire appears circular in shape but the LEDs and reflector are square in nature. LEDs are mounted in a linear fashion on each side and shine inward to a reflector that forms the beam pattern.

According to VP of Technology Mike Mundloch, Everbrite's key innovation is in the reflector. He states, "We can do customized beams by changing the length and shape of the reflector." Mundloch also points out that dealing with the reflector in the prototype stage is far easier than dealing with a TIR. And Mundloch believes the company may be able to ultimately use a molding approach to manufacture reflectors. The company hopes to ship production units of the PSL125 in the fourth quarter of 2010.

Nano-patterning boosts LED efficiency

A variety of nano-patterning technologies can be used to enhance the light-extraction efficiency of LED chips, according to **KI DONG LEE**, **ROBERT SJÖDIN** and **TORBJÖRN ERIKSSON**.

The LED market is growing explosively, driven by widespread use in backlighting of LCD TVs and the potential replacement of incandescent and fluorescent lamps. The commercial success of LEDs has been relying on the ceaseless improvement in all aspects of LED technology spanning epitaxial growth, chip processing, and packaging.

LED efficiency measures the final light output for a given electrical input, and is determined by four factors: internal quantum efficiency, extraction efficiency, electrical efficiency and package efficiency. Internal quantum efficiency measures how many photons can be generated for given electron-hole pair generation, and is determined mostly by the quality of the epitaxial layer. Light-extraction efficiency defines how many photons of those generated can escape the LED device, and is determined by the chip and package structure.

Conventional approaches to enhance efficiency

LED chips have inherently low extraction efficiency due to the high refractive index of the semiconducting media. Most generated light is reflected internally at the semiconductor-air interface, and only a small fraction of light can be extracted into the air. Many ideas have been proposed to increase LED efficiency through enhanced light extraction. Two major approaches adopted in the LED industry are random texturing and patterned sapphire substrate (PSS) technologies.

It is important to consider actual chip designs in order to decide which strategy for light extraction is the best. LED chips are divided into four different categories depending on the existence of a sapphire substrate and on the bonding method in the package (Fig. 1).

In a conventional chip (Fig. 1a), the p-GaN layer is positioned at the top side together with the p- and n-electrodes. These electrodes are connected to the leads of the package by wire bonding. In a flip-chip LED (Fig. 1b), the sapphire substrate faces up, and the electrodes are bonded to the sub-mount by flip-chip bonding.

Removal of the sapphire substrate and the use of a conducting support have many advantages in light extraction and heat dissipation. Laser-lift-off technology is normally used to remove sapphire substrate from the epitaxial layers, forming a thin-film LED.

In a vertical thin-film LED (Fig. 1c), the n-electrode is positioned at the top side and the supporting conductor works as a p-electrode. The electric current flows vertically, which is another advantage of this approach in terms of current spreading.

When the LED chip without a sapphire substrate is bonded via flip-chip bonding, it is called thin-film flip-chip LED (Fig. 1d). In this case, both the n- and p- electrodes are positioned at the same side like conventional or flip-chip LED.

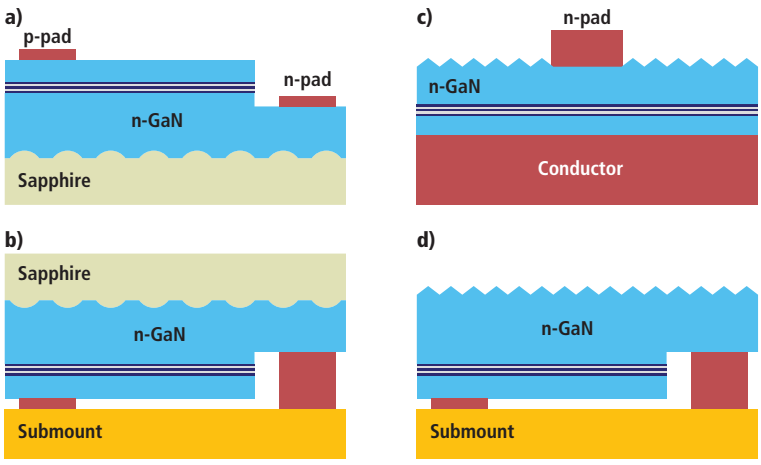

FIG. 1. LED chip structures: (a) Conventional LED chip with patterned sapphire substrate (PSS). (b) Flip-chip LED. (c) Thin-film vertical LED with n-GaN texturing. (d) Thin-film flip-chip LED.

In conventional chips (Fig. 1a), random texturing of the upper p-GaN layer is an industry-dominant way to increase the light extraction. The texturing is usually carried out in situ during the epilayer growth by MOCVD. It is a cost-efficient method and no additional texturing process steps are required. However, with increasing substrate size, loss in throughput and uniformity may appear as a problem.

In the case of flip-chip or thin-film LEDs, the n-GaN layer faces up, and this layer should be made rough or patterned to increase light extraction. A wet-etching technique is usually employed to texture the n-GaN surface. Most of leading HB-LED

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manufacturers employ this technology, and thin-film flip-chip LEDs with n-GaN texturing is known to have the highest extraction efficiency of over 80%.

Patterned sapphire substrate (PSS) technology is another approach widely adopted in LED manufacturing together with random texturing. The idea is to grow GaN epilayers on micro-patterned substrates instead of on a flat substrate. Two benefits are expected, the first of which is an increase of internal quantum efficiency due to lower threading-dislocation density in the epilayer grown on PSS. The second is an increase in extraction efficiency due to the fact that the patterns at the epilayer-sapphire interface work as scattering centers or refracting bases, reducing the total internal reflection.

Nano-patterned sapphire substrates

There are several new approaches to increase LED efficiency that employ nanopatterning. The first of these, nano-patterned sapphire substrate (NPSS), can be considered to be an extension of conventional micro PSS. However, since NPSS requires higher-resolution lithography, it should have a clear advantage compared with micro PSS. Although none of the LED manufacturers are known to use NPSS in production, several research papers exist showing promising results indicating that NPSS can have higher efficiency than micro PSS by around 10-20 %.

From the viewpoint of a manufacturing process, NPSS may have further advantages beyond the efficiency increase. Compared with micro PSS, it has much smaller structures so that the time required for sapphire etching can be reduced. Considering the epilayer growth, NPSS also requires less time to reach planar epilayers. Another interesting idea is to combine NPSS with laser lift off. By doing this, one can generate textured patterns on vertical or thin-film LEDs by the LLO process alone, without requiring further lithography and etching steps. Moreover, the epilayer grown on NPSS may have better epilayer quality, which adds further potential to increase the efficiency.

Photonic crystal (PC) technology

Photonic crystal technology has been researched over a long period as a candidate for the ultimate light-extraction technology.

FIG. 2. High-volume Sindre nanoimprint lithography (NIL) manufacturing tool.

The idea of photonic crystal is to use a periodic or quasi-periodic structure, with dimensions comparable to the wavelength of light, as a diffraction grating in order to convert the guided modes into leaky modes, resulting in an increased light output.

Despite extensive R&D efforts in academia and industry, the PC approach is not widely accepted by the LED industry. Different results have been achieved depending on the LED chip design, how the photonic crystal has been applied, the encapsulation method and so on. In some cases the results are better than conventional random roughening, and in other cases they are not. Philips Lumileds recently reported in the Nature Photonics journal that PC can have higher extraction efficiency than random roughening for very thin (~700 nm) GaN layers without encapsulation.

It is likely that PC technology provides a good advantage for an LED chip without encapsulant and phosphors. However, for white LEDs, which use an encapsulant containing phosphors, there seems to be no advantage in using the technology. The merit of PC disappears because phosphors within the encapsulant randomize the light direction.

Considering this, it seems that full advantage of PC may be utilized mainly when the LED chip is packaged to emit light directly into the air. There may also be other advantages using PC, for example in binning, yield or throughput, which could compensate the higher processing cost than random roughening.

Already today, some LED manufacturers use PC technology to enhance light output. Luminus Devices uses PC technology for their large-area, high-power LEDs used in various projectors and backlighting units for TVs. The PC structures are fabricated by nanoimprint lithography (NIL).

Epitaxial lateral overgrowth (ELO)

Epitaxial lateral overgrowth (ELO) is not a brand-new technology and has been used for the production of blue laser diodes. The idea is to embed patterned dielectrics (SiO_2 or SiNx) within the GaN layer. Threading dislocations (TD) are blocked by the embedded dielectrics, preventing them from growing above the dielectric layer. GaN epilayers can grow only through the opened area in the dielectric, and merge laterally together. The result is a considerable reduction in TD density. ELO has not been a choice for LED production because it is obviously a high-cost technology. However, it is getting attention again since it can be a route

to solve many issues in LED e.g. efficiency droop, non-polar GaN, and growth on silicon substrates.

Recent LED research concerning ELO has investigated the effect of nanopatterned dielectrics. An interesting point is that a nanopatterned dielectric can work as an embedded photonic crystal, with a possibility of better light extraction than a micropatterned dielectric. Actually, a micropatterned dielectric can cause a detrimental effect on the light extraction. Promising results have already been reported in nanoscale ELO. However, it is uncertain if ELO will be widely used in the LED industry for volume production based on 2-inch sapphire substrates because the processing costs are rather high. However, the coming shift to production based on larger-diameter (4- or 6-inch) wafers opens up interesting possibilities for using the technology to increase the LED efficiency.

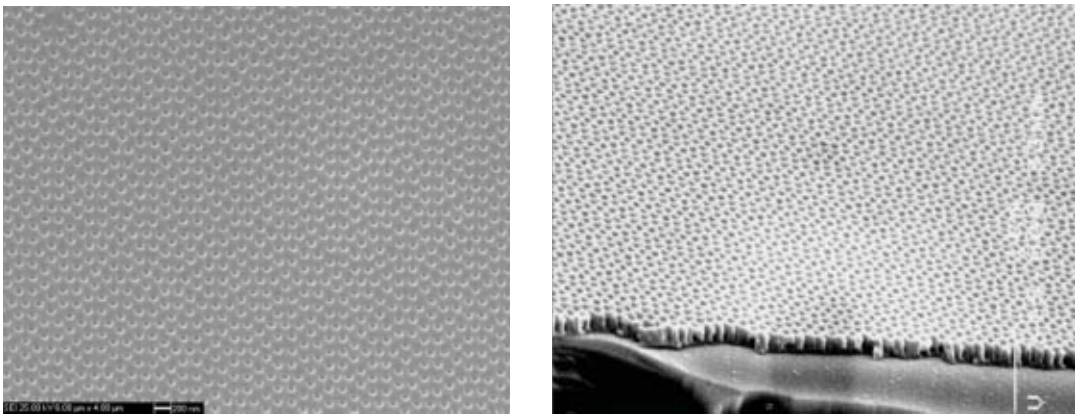

FIG. 3. SEM measurements of a quasi crystal pattern printed on a GaN epi-layer. The pattern covers the entire surface despite the growth defect shown to the right. The hole diameter is 90 nm.

Surface plasmon

Surface plasmon (SP) is a quantum of collective electron oscillation at the surface of metal. In nano-size or nano-patterned metal, its effect is greatly enhanced. SP is one of the hot research topics in the nanophotonics field. The technology is already being used commercially for bio-sensing and in the heart of photonic integrated circuit research. Several researches have also shown that SP can enhance the efficiency of solar cells. Several research studies have showed an increase in LED efficiency using SP technology. It has been considered that surface plasmon can interact directly with electron-hole pairs in the quantum wells (the light-emitting region within the LED chip) to enhance the radiative recombination rate. However, one practical problem is that the metal layer must be less than 100 nm from the quantum-well region. When the metal layer is positioned on the top side of the LED, this restraint means the p-GaN layer must be very thin, which in turn makes current spreading difficult.

Nanoimprint lithography

Nanoimprint lithography (NIL) offers various advantages when it comes to LEDs. Nanopatterning of substrates used for LED manufacturing has proven to be a challenge due to waviness and presence of defects. Optical lithography methods suffer from loss of focus due to these irregularities, and e-beam lithography is too slow and expensive. Conventional NIL employing hard stamps also fails due to the presence of the mentioned defects.

The imprint process developed by Obducat for nano-patterning of LEDs is based on a two-step process. First, the stamp is replicated into a proprietary soft-polymer film to form an Intermediate Polymer Stamp (IPS). This IPS is then used in the second imprint step to replicate the pattern onto the target substrate using the proprietary Simultaneous Thermal and UV (STU) process technology, which enables simultaneously combined thermal and UV nano-imprint lithography.

The patented IPS technology enables contamination control and increases the master stamp lifetime by avoiding contact between the stamp and the substrate. It therefore greatly impacts the overall costs associated with NIL, making the solution very cost efficient.

Another Obducat technology is Soft Press, where pressure is applied to the stamp and substrate using compressed air, ensuring pressure uniformity over the entire imprint area. This allows stamp and substrate to conform to each other, eliminating negative effects from thickness variations, bow or waviness in stamp or substrate. Soft Press enables thin and uniform residual layer over large areas, which is critical for high-resolution printing and pattern transfer fidelity.

Based on the nano-patterning requirements set by the LED industry, Obducat has developed high-volume Sindre NIL manufacturing tools (Fig. 2), which utilize the three technologies described above and have a throughput of 30 wafers per hour. Fig. 3 shows imprints on GaN substrates, produced in a Sindre 400 system.

Summary and conclusion

There are many opportunities to further increase the LED efficiency by nano patterning. Photonic crystal (PC) on the chip surface has been researched for many years, but so far, it has not been good enough to overcome the higher process costs involved compared with random texturing. The concept of PC may survive combined with nano-patterned sapphire substrate (NPSS) and epitaxial lateral overgrowth (ELO). NPSS has the biggest potential for commercial success because it is a natural extension of existing technology, and many studies have shown promising results. It is also expected that NPSS may have further advantages purely in terms of processing compared with micro PSS. Due to its cost-effectiveness combined with superior processing performance, nanoimprint lithography will play a crucial role in moving the LED industry into a new realm of nano-patterned LEDs with ultra-high efficiency.

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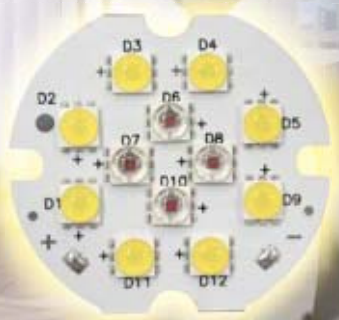

Lm/Watt 85
CRI> 90

Crab module series

ProLight Opto has recently launched a new module series (Crab module series) for commercial lighting applications, especially for incandescent bulbs and downlights replacement.
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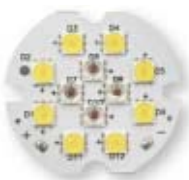
Picture			
Dimension	Diameter 31mm		
Power	6W	9W	12W
Flux(lm@2600k)	500	750	1000
lm/watt efficiency	85 lm/W		
CRI	>90		
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interview | **MARK SWOBODA**

Intematix to take materials-centric approach under Swoboda

Mark Swoboda, the new CEO of Intematix, will leverage the company's materials heritage to capitalize on the value proposition of phosphors and phosphor-based lighting components, reports **MAURY WRIGHT.**

In August 2010, Fremont, California-based Intematix appointed Mark Swoboda as CEO. In an interview with *LEDs Magazine*, Swoboda described his vision for a company focused on deriving value from its materials expertise in general and phosphors in particular. On the subject of LED-based solid-state lighting (SSL), Swoboda said, "What the consumer sees is based on how the phosphor performs."

Intematix certainly has a legacy in materials science and phosphor development. But in the SSL space, the company has also developed packaged multi-chip LED arrays, light engines and even light sources. However, it appears that phosphors, and new ways to supply phosphors to customers, will be the forward focus.

"If you understand the value chain, you realize that the quality of light is almost entirely controlled by the phosphor material system," said Swoboda. "By quality of light I mean the energy efficiency, the color of light, the color rendering, the color consistency, and the lifetime."

Swoboda recognizes the value brought by blue LEDs that excite the phosphor in white-light applications. But he insists that the phosphor is the key to SSL despite the fact that many people overlook phosphor as part of the value chain.

Swoboda certainly has a broad perspective from which he can make SSL-related observations. Most recently Swoboda worked for LED maker Bridgelux, including a stint as CEO before Bridgelux brought Bill Watkins on board earlier this year. He also worked at Philips Lumileds and its predecessor, Hewlett-Packard.

"Many of the companies that I've worked for, or with, in the past are Intematix customers," said Swoboda. "If you are an LED maker you understand how important phosphor is to making a white LED."

Still Intematix's most recent major product announcement, in April 2010, was focused on a packaged LED array (www.ledsmagazine.com/news/7/5/3). When asked about that array, Swoboda chose to first re-emphasize the phosphor subject. He said, "There is no question that the company's DNA and its core, and foundation, and strength, is in material systems. The company made a wise decision many years ago to focus on developing phosphors for LEDs."

Intematix also makes phosphors for other light sources such as compact fluorescent lamps. But the primary focus is clearly SSL.

Pressed on the LED array announcement, Swoboda said, "The question is, do we have any business being in the package LED business?" He provided his own answer: "Intematix has some ability to bring additional value in the array, based on its current product family. But if we're to be in the packaged LED business, there has to be some strong value proposition that we bring to market."

Swoboda pledged to support existing customers in all existing product areas including arrays, saying, "We have a customer base and we're not going to walk away from it." He also mentioned that startup companies often take steps to grow their top-line revenue, even if the endeavor is a little outside the core business plan. But, he said, "We're at a point where we can focus in on the enabling materials."

When asked about the light engines and modules in the Intematix product line, Swoboda said, "There is potentially a reason to be in the system-level business, but part of that is to almost use [these products] as a technology demonstrator for our customers and investors." He suggested that such products could become reference designs, adding "It's really about proving to the market that you can enable more efficient downlights, or linear lights, or area lights."

Phosphor delivery

So far, Intematix has typically supplied phosphors in powder form, relying on engineers in the customer base (typically LED manufacturers) to devise ways to effectively apply the product. Looking forward, Swoboda clearly intends to insert Intematix more deeply into lighting applications.

"We may consider form factors other than powders," said Swoboda. "We are focused on bringing phosphor-based lighting components to the market that will enable general lighting applications. And for the most part they will probably enable remote-phosphor applications."

Swoboda is emphatic in his belief in

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

the remote-phosphor approach. "In the lighting market we're going to see a trend toward remote-phosphor lighting systems," he said. "We believe that we can improve the efficiency of lighting systems by anywhere from 10 to 30% over the next 15 to 18 months." And this prediction is based on today's LED chip performance, but of course LEDs will get better over that same time frame.

Asked about what forms Intematix's phosphor technology could take, Swoboda said, "We could have a phosphor plate, a phosphor dome, a phosphor bulb, or a phosphor lens." Clearly the company is looking at phosphor-coated products that it can sell to luminaire and lamp vendors.

New markets

As for market segments, Intematix today has phosphor business in both the backlighting and general lighting applications. That focus will continue, but the company is looking at symbiotic phosphor-centric markets.

Nichia warns rivals over red-emitting phosphors

In June 2010, Japanese LED maker Nichia issued a non-too-subtle warning to rival manufacturers that it believes could be infringing its phosphor-related patents relating to CASN and S-CASN materials. The announcement (www.nichia.co.jp/en/about_nichia/press.html) concerns phosphors that emit red light, and which are typically used in combination with a yellow-emitting phosphor to achieve warm-white LED light.

Specifically, Nichia says that it owns patents covering phosphors with the general formula CaAlSiN3:Eu, also known as CASN or S-CASN. The patents, also covering LEDs using these phosphors, have been filed in Japan, USA, Europe, China, Korea, and Taiwan. Several of the US patents listed are owned jointly by Nichia and Dowa Electronics Materials Co., Ltd.

Nichia said that it has "never licensed any of these patents to others," adding "Nonetheless, CASN phosphor and S-CASN phosphor have been manufactured in large quantities without Nichia's authority, and LEDs using these phosphors also have been manufactured in large quantities as well."

Nichia concluded by saying that it "expects that these patents will be respected," which is an ominous statement considering Nichia's history in involving itself in patent litigation. ◄

Swoboda said that Intematix has developed "printing and painting techniques" using phosphor paint or ink. "With our phosphors, we can print in high-definition color," he said. "You can create 80 or 90% of the CIE chart – a color gamut wider than high definition."

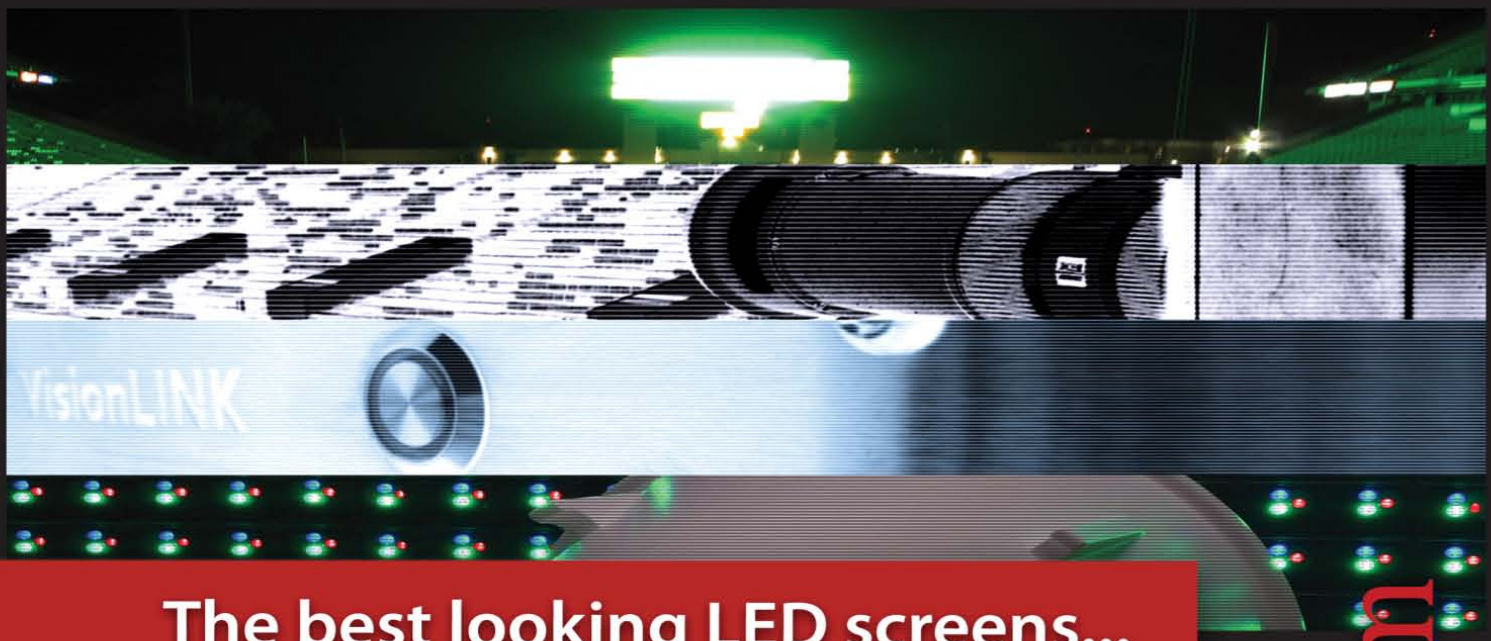
The company is looking at the signage market as a potential for the printing and painting techniques. Swoboda said, "We can enable a sign that is significantly more efficient than a fluorescent-based box sign, and even 50% more efficient than a white-LED-based sign."

Intematix is also looking at other advanced technologies. "We do have a program going on in quantum dots. It's a natural extension for us," said Swoboda. "There's even the potential for us to take a closer look at OLEDs based on our material systems that might be complimentary to what's already been developed."

The company will face a challenge having its value proposition recognized. Swoboda admitted as much, citing as a fictitious example, what he called a "hero device" that theoretically delivers 160 lm/W. "No one ever talks about the phosphor contribution to that performance. Everyone assumes it's in the epitaxy and the chip," he said. "And yet there is a huge phosphor contribution to the performance of those devices."

Still Swoboda is confident in the phosphor-centric tack. "Our customers know who we are," said Swoboda. "I think as we transition to offering phosphor-based lighting components to the market, the value proposition will emerge. You can take blue LEDs, and put them behind an Intematix phosphor disk or phosphor plate or phosphor plastic. I think our value contribution will become more apparent." ◄

• Ilkan Çokgör, former director of marketing & business development at Intematix, recently joined Everlight Electronics Co., Ltd as Vice President of Global Marketing.



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design forum | CIRCUIT PROTECTION

Circuit-protection devices guard against electrical transients

Open LED protectors can cope with significant over-voltage transients and keep a series string lit when one LED fails as an open circuit, say **PHILLIP HAVENS**, **JIM COLBY**, and **TEDDY TO**.

LEDs are fragile devices subject to heat, mechanical shock, electrostatic discharge (ESD) threats, and lightning induced surges. The increasing use of LED strings for solid-state lighting (SSL) and backlit displays is requiring more attention by designers to LED string reliability. High brightness LEDs built on sapphire substrates are especially sensitive to electrical transients. Even in household applications, LED strings require ESD protective devices to assure long, reliable operation of the entire assembly. In the absence of such protection, if one LED in a series string fails and opens the circuit, all the other LEDs turn off. Designers should consider circuit protection options from the AC line through to the individual LEDs.

A wide variety of protective devices can be considered for the power supply and LED driver. The circuit in Fig. 1 is an example that illustrates switch mode power supply (SMPS) protection in an LED street-lighting system. In this circuit, the AC fuse provides basic fire protection against major system failures that could cause an overcurrent condition but must be able to tolerate between 3kA to upwards of 6kA surges without opening. The DC fuse is for fast acting overcurrent protection in the event of a downstream component failure in the DC-to-DC converter or LED driver circuit.

On the AC input side of the circuit, there is also a need to handle overvoltage events and transients. These are often caused by nearby lightning strikes, but can also be generated by switching transients on power lines. The typical protection devices for these overvoltage conditions are metal oxide varistors (MOVs) possibly combined with transient voltage suppressors (TVSs). Circuitry for power-supply protection also requires line isolation from ground to protect against possible shock hazards. The safety requirements are defined in the regulatory specifications IEC/UL 60950-1, UL 1449, and IEC/UL 6500. Fig. 2 shows a solution that satisfies these requirements. The design combines an MOV with a TVS device.

In addition, overvoltage protection should be considered for the LED driver IC. Proper decoupling with a capacitor, along with the inclusion of a TVS device rated at the line driver supply voltage, will provide a very stable design.

Some LED driver manufacturers include circuitry that senses an open LED string, but that should not be confused with protecting the string or keeping it operating if an LED fails open. Robust designs must both protect the string from transients and ensure normal operation in the case where individual LEDs fail.

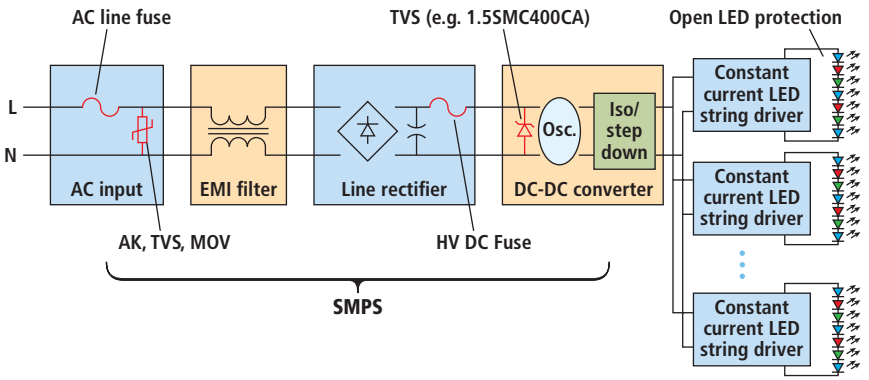

FIG. 1. This example of an LED street lighting circuit includes protective devices associated with the switch mode power supply (SMPS).

Individual LED protection

A bypass protection device within an LED string (Fig. 3) will allow the string to continue functioning in case a single LED fails in an open state. This will also help protect the LED driver by limiting any excess current or voltage demands on it by the loss of an entire LED string.

When it comes to protecting individual LEDs, and the series circuit leg in which a string of LEDs is installed, selecting the right protective device is crucial. This requires an understanding of potential LED failure mechanisms and how different types of protective devices work. This understanding will help circuit designers select the appro-

TEDDY TO *is the Product Manager, PLED LED Protection Devices at Littelfuse.* PHILLIP HAVENS *is the Technical Marketing & Applications Manager at Littelfuse.* JIM COLBY *is the Manager, Business and Technology Development for the Electronics Division of Littelfuse.*

priate device, including one that will keep a series LED string operating when one LED fails as an open circuit.

First let's consider how LEDs are controlled and the possible failure modes. A series-connected LED string is powered by a constant current generated by a switch-mode power supply that drives them to full brightness, color, and intensity. This constant-current supply circuit provides better control of LED group brightness as well as a more uniform LED-to-LED brightness.

LEDs are fragile solid-state devices – essentially diodes, structured as p-n junctions that emit light when forward biased. The main LED failure mechanisms are mechanical and thermal in nature, involving thermal cycles, thermal shock, and high temperatures that cause wire bonds to age and fail. As the metal oxidizes and becomes brittle over time, the likelihood of an LED failure increases. ESD events or surges induced by nearby lightning strikes are another common cause of LED failure.

Parameters for protection devices

The principal parameters in selecting LED protection devices are individual LED current and power ratings, forward operating voltage, and the LED driver compliance voltage. Typical HB-LED power ratings are between one and three watts. The maximum current draw of an HB-LED at its wattage rating can be determined simply from:

I = P/Vf

where I is the current, P is the LED wattage rating and Vf is the LED forward voltage. LEDs are available in different wattage ratings so these values will differ accordingly. Also, LEDs that emit at different wavelengths (colors) have different voltage drops. For instance, a red LED typically has a lower Vf than a white LED and will therefore draw more current.

A major reliability issue is the continued operation of the LED string if one LED fails as an open circuit. In applications that demand a highly reliable light source, this can be crucial. Many outdoor applications such as street lights are located off the ground so that readily available access can be problematic. A single LED open circuit failure in a series string can result in major expenses and inconveniences because the entire assembly would have to be serviced.

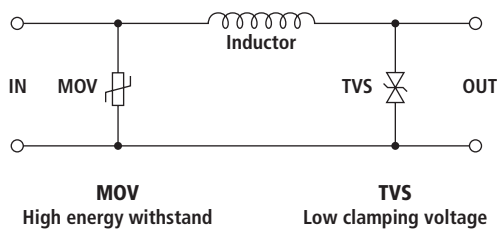

FIG. 2. A MOV and TVS provides power-input overvoltage protection for LED lighting.

Bypass protection devices

To protect an LED and prevent an entire LED series string from going off when a single LED fails as an open circuit, a bypass protective device needs to be installed across the LED terminals. There are a number of devices that might be considered, including MOVs, SCRs, zener diodes, polymer ESD protectors, and open LED protectors.

MOVs are best suited for relatively high-energy power line transients typically caused by lightning strikes and the switching of large inductive loads. Unfortunately, they do not respond quickly enough to protect an LED from lower level transients that could cause an LED failure. In addition to that shortcoming, if the LED does fail open, the MOV does not provide a path for the current so the entire LED string would turn off. The resulting heat from an MOV could also be problematic for the LEDs.

An SCR can route current around a failed LED to keep the rest of the string lit. Still, these are physically large devices, and they typically require a resistive voltage-divider network to set the trigger voltage. The variation of SCR triggering voltage at different temperatures can be quite large. In addition, the reverse blocking voltage is too high, so an SCR cannot provide reverse polarity protection.

Zener diodes can be used to bypass an open LED and are typically much smaller than an SCR, although Zener diodes have other drawbacks. When an LED fails as an open circuit, the zener diode must conduct all of the current in the series string. Most zener devices have relatively low current ratings, so their life will be short in this type of application. The zener mode would also cause a micro-environment thermal event that could lead to further LED failures.

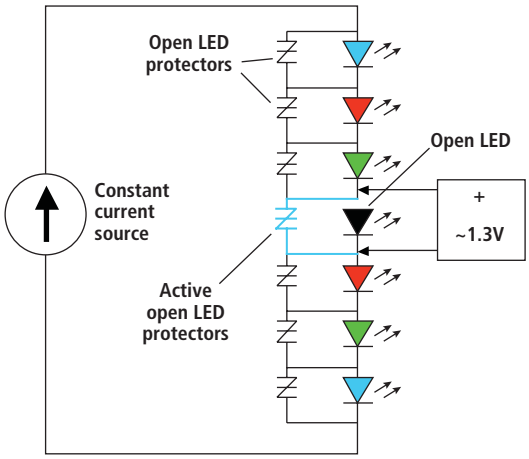

FIG. 3. Protecting individual LEDs in a string with the appropriate bypass protective device not only keeps the string lit, but also helps protect the LED driver from excessive current or voltage demands that can be caused by LED failures.

Polymer ESD protectors are made for high-speed digital circuits, not the protection of DC lines, as in the case with LED strings. They have higher dynamic resistance than a silicon device, so their clamping voltage is much too high to protect a delicate LED. Moreover, they cannot provide surge protection, nor reverse polarity protection.

Open LED protectors are designed specifically to keep the rest of a series LED string in operation when one LED fails open. They are compact silicon-based devices that are installed across each LED terminal. Acting as a bypass devices, they route current around an open LED to keep the rest of the string lit. Some open LED protectors also provide ESD/lighting and reverse polarity protection, which reduces lighting circuit costs by eliminating the need for additional protection components.

Open LED protector operation

An open LED protector is an internally

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triggered two terminal device installed across an LED, which automatically resets if the LED heals itself or is replaced. This protector is a voltage-triggered switch with low leakage on the order of microamps that becomes a low-impedance switch when it is triggered on (Fig. 3), which minimizes power consumption. An LED in the on-state drops approximately 0.7V, which is not sufficient to turn on the protector device. Once an LED fails open, there is sufficient circuit voltage to trigger the protector to the on-state (the compliance voltage as supplied by the LED driver circuit). The LittleFuse PLED6 series also features built-in surge immunity, which helps protect the LED from surges induced by nearby lightning strikes or ESD events.

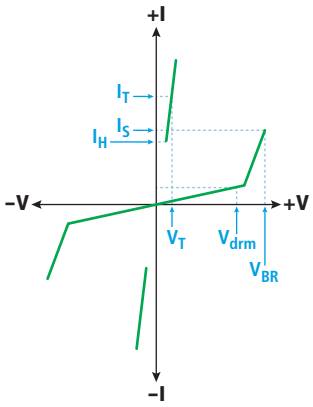

FIG. 4. The graph illustrates typical open LED protector V-I characteristics.

Using a PLED6 Series device as an example of a typical open LED protector, Fig. 4 shows the key parameters are V_{BR}, I_S, I_H, I_T, and V_T, as shown in the V-I curve. V_{BR} defines the region from the off-state voltage to the breakdown voltage rating of the device. In the off-state, V_{BR} is the continuous peak combination of AC and DC voltage that may be applied to the device, which results in less than 5μA conduction through the device. (Various minimum V_{BR} ratings from 6 to 33VDC are available.) I_S is the value of current that causes the device to switch from the off-state to the on-state when the minimum V_{BR} is applied. Typically, the maximum I_S value is 100mA. Holding current (I_H) is the minimum current required to maintain the device in the on state (typically, 5mA). On-state voltage (V_T) is the maximum voltage across the device during full conduction. I_T is the maximum rated current that can be conducted through the device during the on-state for two seconds (1A max). Usually, the LED string current is much lower than this, allowing the open LED protector to remain on indefinitely.

There are slight differences in V-I curves from one each series of open LED protectors as indicated in Figure 5 for the Littelfuse PLED5 series. The 3rd quadrant reaction demonstrates the reverse polarity protection for this series.

Since a big concern in LED operation is thermal conditions, another advantage of these open LED protectors is a wide oper-

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ating temperature range (-40°C to +150°C). In addition, they have a low on-state voltage (about 1.5V) and a low off-state current. Therefore, when the protector turns on, it has a very low thermal dissipation.

Open LED protectors also work well with various LED brightness control methods. Brightness is best controlled by pulse width modulation (PWM) with the switching frequency typically between 60Hz and 1000Hz but the PWM can go much higher. PWM dimming provides a more efficient and more precise dimming control than merely limiting the DC current, which can cause unwanted color shifts. Plus, a linear power control lowers energy efficiency. In any case, the open LED protection device will not interfere with either dimming strategy. The open LED protection devices are compatible with LED switching speeds up to 30kHz, which eliminates any potential negative effects such as flickering.

Ideally, in an open LED protection scheme there is one protective device across each LED. However, a lower-cost protection scheme may work too. For instance, it's possible to install one PLED across two LEDs in series when the proper open LED device is selected. One LED failure will result in two LEDs going dark, but this cuts protection costs in half.

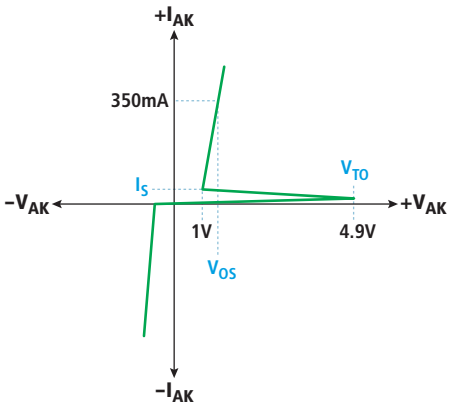

FIG. 5. The third quadrant of this V-I curve illustrates reverse-polarity protection capability.

Protection keys long LED service life

LEDs require ESD protection, particularly in high-reliability applications such as safety-critical lighting deployed in harsh environments. In truth, outdoor LED lighting installations can actually be less reliable than conventional lighting, unless designers add the proper circuit protection to guard against the most severe overvoltage conditions.

The first line of defense is a good circuit-protection scheme, stretching from the input power supply to individual LEDs. Open LED protectors can cope with significant overvoltage transients and keep a series string lit when one LEDs fails as an open circuit. As beneficial as this protection may be, it is still just one part of a total solution that should include fuses, MOVs and TVS devices to protect the SMPS and LED driver.

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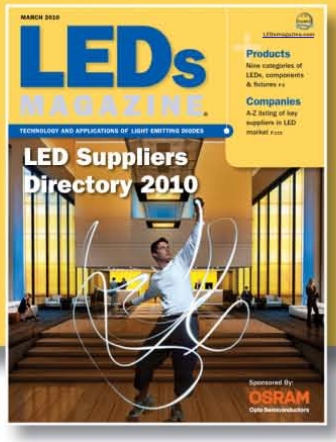

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Compatibility and reliability are key factors in the design of LED lighting devices and systems

For everyday operational scenarios, LED lighting devices and systems must be compatible with power systems and electrical infrastructure, explains **PHILIP KEEBLER**.

The use of electronic systems and components in the design, development and manufacturing of lighting technologies is changing the future of lighting devices and systems. Much progress has been made, from the early days when electronic fluorescent-lighting ballasts were just beginning to use diodes and transistors to rectify AC line power, to internal DC power with inversion to high-frequency AC power to drive high-efficiency T8 lamps. Nowadays, designers of electronic lighting devices are no longer just designing electronic ballasts—they are designing intelligent AC-to-DC converters, some with sophisticated internal microprocessor-based systems for lighting control and dimming systems.

Ironically, designers are also gaining much experience in utilizing light-generating semiconductor diodes—LEDs—to design LED light engines, or arrays of LEDs. Intelligent converters, called electronic drivers, are used to power and control LED arrays ranging from a few tens of LEDs to as many as several hundred LEDs. The dynamics of designing a set of electronics to drive a light source has gone far beyond discharge tubes filled with gas mixtures at various pressures. With LED lighting devices and systems, the LED light sources are part of the electronics package.

This new boundary places additional challenges on designers and integrators of LED lighting devices and systems. With discharge-tube applications, ballast designers were only concerned with the electronics inside the ballast can. However, with LED lighting devices and systems, product designers must extend their thinking to the LED light source. The LED light source is an array of LEDs connected in a certain circuit configuration with some series-parallel arrangement and some electronic components designed into the mix. With this type of load on the driver, designers need to know what types of DC disturbances the LED array might be exposed to when the driver's input is subjected to a common everyday electrical disturbance.

> "When lighting devices fail prematurely or malfunction at an early age, thoughts of energy efficiency and savings are no longer so important when the lights will no longer work."

Compatibility with power systems

The science of converting and delivering power to LED arrays is really only part of the global picture. Lighting designers, lighting specifiers, and end users demand LED lighting devices and systems that are reliable and compatible with the power system on which they rely. The power system includes the electrical infrastructure inside the customer's premises and the utility power system outside.

EPRI research has shown on several occasions that a facility power system owned and operated by the customer typically has a number of wiring and grounding errors. When some common everyday electrical disturbances occur outside the customer's facility on the utility power system, the wiring and grounding errors inside the customer's facility exacerbate the disturbance increasing the likelihood that it will cause permanent damage to the customer's electronic lighting device. LED lighting devices and systems must be able to perform in common everyday electrical environments. These electrical environments include areas inside and outside residential, commercial, and industrial facilities and even out on utility power poles for LED street and area lights.

Electric-powered lighting has become a necessary part of nearly every aspect of life during both day and night. When lighting devices and systems fail unexpectedly, end-users get upset. Business operations are often interrupted. Manufacturing facilities may have to send plant workers home if lights are not brought back up within a certain time to avoid unsafe working conditions. Electrical events caused by thunderstorms, traffic accidents involving power

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poles, construction crews penetrating underground electric services, and animals crawling around on distribution transformers and power lines are just a few examples of everyday problems that will always occur. Some of these incidents may cause temporary problems with utility power systems, resulting in unexpected turn-off or electrical disturbances that cause damage to electronic lighting devices.

In today's energy conscious world, energy efficiency and savings are extremely important in reshaping our planet and environment towards a greener society. With lighting representing about 23% of the grid load, all stakeholders are aiming for the development and use of electronic lighting devices that operate at higher efficiency levels and can be utilized as the fifth fuel when a reduction in lighting load is needed during peak operating periods. However, when lighting devices fail prematurely or malfunction at an early age, thoughts of energy efficiency and savings are no longer so important when the lights will no longer work.

Upcoming technical articles

Our intention is to publish a series of articles that will address several important topics related to the reliability and compatibility of LED lighting devices and systems. The various topics are shown below:

System compatibility for LED lighting devices and systems: We will define the concept of system compatibility and answer the following questions: Why was it developed? What does it mean for today's electronic products? How can manufacturers utilize EPRI to apply this concept to their products? How do manufacturers benefit from using the concept? How can the LED lighting device/systems industry benefit from this concept? How has it already helped hundreds of product manufacturers including manufacturers of other electronic lighting products?

System compatibility testing: An overview of each part of the testing program will be described, including how each part and test can be applied to LED lighting devices and systems.

Examining the economic benefits of compatibility testing: Discusses why manufacturers should invest in compatibility testing for their LED lighting device and system products. Many are unfamiliar with the economic benefits of this concept. The testing results, characteristic of real-world electrical environments, can be used to help educate those involved in planning and setting product warranties.

Using compatibility testing combined with LED performance standards: Describes how compatibility testing can be combined with the use of LED performance standards such as LM-79 and LM-80 to gain further knowledge into LED lighting device and system performance in common everyday electrical environments.

Examples of design improvements from compatibility testing: Describes example findings from past experiences in testing electronic products (including electronic lighting products) for compatibility. This will include some of the design improvements identified during these tests, how they were implemented, and how the improvements were verified.

Compatibility testing and emissions: Describes the importance of including different types of emissions tests in the compatibility testing program. Many manufacturers do not understand how radiated and conducted emissions relate to the other objectives of compatibility testing, and how a focus on emissions testing can help them to ensure that they do not learn one day that one of their products has been found to exceed a prescribed emissions limit promulgated by the FCC or other regulatory agency.

Immunity and electrical disturbances: Describes why immunity testing is so important to the life of LED lighting devices and systems. This will discuss both destructive and non-destructive electrical disturbances and why they are applied to products, including some examples of performance data outcomes.

Applying the compatibility concept to lighting controls and demand response systems: Whether a lighting control or demand response system utilizes a hard-wired or wireless control (or communications) media, proper consideration of compatibility of the LED lighting device and system including the controls is critical to the survivability of the whole system.

Utilizing compatibility test results in modeling reliability: Describes how compatibility test results can be used as input data in developing reliability models for LED lighting devices and systems. Today's manufacturers of LED lighting devices and systems do not have a tool for predicting or studying the reliability of the whole LED product including how each internal and external factor influences the reliability of the product.

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Testing Times: Standards and Measurement Requirements for LEDs and Luminaires

SPEAKERS: *Greg McKee, Labsphere, General Manager System Business Unit*
Rob Leonard, Director of Sales and Marketing for Orb Optronix Inc.

This webcast discusses standards and measurement requirements for LEDs and luminaires, and is applicable to specifiers, designers and manufacturers of LED-based products.

The Future of LED Control

SPEAKERS: *Amanda Beebe, LED Product Manager, Lutron*
Russ MacAdam, Director of Product Development, Lutron

As the use of LEDs is becoming more widespread in both commercial and residential applications, it has become clear that there are many questions about which LED products are compatible with which lighting controls. Learn about existing control protocols and what the industry can expect in the future.

LED Lighting Testing: HAZLOC & EMC Certification

SPEAKERS: *David Schramm, Assistant Chief Engineer, EMC, Intertek*
Lisa-Marie Martin, Senior Hazardous Locations Engineer, Intertek

This webcast discusses HAZLOC and EMC requirements for the U.S. and international markets, and is applicable to engineers testing in potentially explosive environments or testing lighting products for EMC

Optimizing LED Performance Through Heat Management

SPEAKERS: *Martin Schon, Thermal Management Product Manager, Sapa Extrusions*
Mick Wilcox, Director of Marketing, Nuventix

As product designers develop higher powered LEDs for the lighting, medical and home entertainment product markets, thermal management increasingly becomes an obstacle. This Webcast discusses the effect of heat on LED fixtures, and describes how thermal management techniques involving heat sinks and active cooling can assist in product design.

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design forum | **LCD-BACKLIGHT DRIVERS**

System-level approach yields optimized LED backlight design

LEDs are quickly becoming the dominant backlight source for large displays, but design teams need to address thermal, power-management, dimming and other issues to yield an optimal design say **XIAOPING JIN** and **ARKADIY PEKER**.

LEDs are very quickly becoming the LCD TV industry's backlighting technology of choice, and are being incorporated into increasingly larger screen sizes. There seems little doubt that LEDs will be the mainstream light source in all LCD applications due to slim design, low power consumption and the fact that LEDs enable high display performance. System design teams must understand how to optimize LED backlight systems to win in what will surely be a competitive marketplace.

LCD TV system designers face many choices as they develop the next generation of LED-based panels. They must choose between direct-and edge-lit LED backlighting architecture, and select from a variety of dimming technologies, power management approaches and thermal protection techniques. They also must be concerned with accurate and stable color management, and how best to synchronize LED backlight control with video processors for implementation of D1, D2 and D3 backlight-addressing technologies. Moreover designers must choose the optimal LED backlight graphic user interface (GUI).

These decisions become increasingly important with larger TV panel sizes and increasing resolution. As TV panels migrate to full 1080p resolution and as display sizes increase, the quality of the TV backlight unit (BLU) plays an increasingly important role in the overall quality of the displayed image.

There are a number of critical factors to be considered in designing next-generation LED BLUs for large LCD TVs. For instance, there must be a high level of luminance uniformity between each edge and from center to corner, and a combination of high dynamic contrast ratio with deep black levels. Color gamut is also important, and must meet or exceed NTSC requirements. Video quality should support all necessary Motion Picture Response Time (MPRT) requirements, and there also should be a high level of luminous efficiency to minimize power consumption.

To deliver satisfactory picture quality, TV panel manufacturers have a number of options, including edge-lit (D0) or, for increased efficiency, D1 scanning dimming or D2 local or zone dimming. The best picture quality is achieved by using an RGB LED BLU implementation of D3 local or zone dimming of individual R, G, B LEDs.

Beyond image quality, there are a number of significant cost and implementation issues associated with each of the aforementioned BLU designs. Edge-lit and direct-lit LED BLUs have different requirements that impact system-level power efficiency and influence the selection of the power-system architecture.

Designers must select the optimal driving methods for the LED strings. It also is important to select a lighting control system that will manage LED current accuracy over a wide range of input voltages and operating temperatures, with adequate thermal protection. And accurate color management must be ensured in RGB-LED BLU implementations, as well as synchronization of the BLU with the system video processor to implement the BLU addressing schemes (including D0, D1, D2, or D3 dimming approaches).

In general, an LED-based BLU contains multiple strings of white or R, G, B LEDs. The BLU also integrates a lighting control and management function/controller that includes the video processor interface for dimming, plus an ambient light sensor (for W-LED BLU) or RGB color sensor (for RGB-LED BLU) and associated diagnostic functionality. The BLU also contains a power section, which can contain one or more power supply units (PSUs) with thermal management and an interface to the BLU lighting control and management block. The final ingredients are the LED drivers and associated protection schemes.

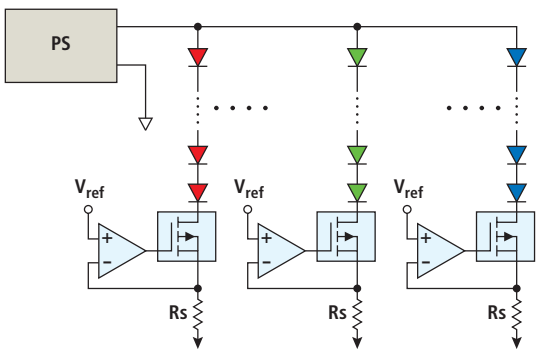

FIG. 1. Single supply drives RGB backlights.

The primary design requirements for the BLU power system are low cost, compact size and a high level of power efficiency, all of which are influenced by the choice of dimming implementation. For example, an edge-lit BLU using D0 dimming will require multiple PSUs with a very low profile, whereas a direct-lit BLU using D2 local or zone dimming will be able to use a smaller

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number of larger, higher-profile PSUs.

To understand the impact of dimming implementations on PSU design, it is important to understand how LEDs work. LEDs are current-driven devices whose output brightness is directly proportional to the forward current, which is driven by a constant DC current source in order to maintain uniform luminosity. A constant current source provides independence from the LED forward voltage differences and forward voltage (V_F) variations as temperature changes. Fig. 1 shows an RGB-LED BLU, in which the RGB-LED arrays are powered by a constant voltage power supply (PS) and controlled by individual current sources. With W-LED strings, each of the colored LEDs would be replaced by white LEDs.

For the RGB-LED BLU implementation illustrated in Fig. 1, there is a trade-off in power efficiency. The PSU must support the LED array (string) with the maximum total V_F. That would result in excessive power dissipation due to the V_F difference of colored LEDs and the V_F difference of same-color LEDs. Both of these differences are caused by LED manufacturing variations.

For example, a Lumiled red Luxeon emitter has typical V_F of 2.95V, and a green LED has a typical V_F drop of 3.99 V. If we assume that there are 10 LEDs per array and the nominal current is 0.35 A, the red array voltage drop is 29.5V and the green array voltage drop is 39.9 V. As a result, the PSU maximum voltage would need to be at least 39.9 V, which would result in excessive power dissipation for the red array, with Pd equal to (39.9 V-29.5 V)*0.35 A = 3.64 W.

To improve power efficiency, system designers can use an individual DC/DC converter on each R, G and B array/string, and transform the converter to a constant current source by regulating the voltage across an LED string current sense resistor. While this is a more expensive approach, it results in significantly better power efficiency and can also be used for W-LED implementations, in which each of the colored LEDs is replaced by a white LED.

Thermal management is another important design consideration. LED BLUs must be capable of managing the positive thermal co-efficient of the LEDs. This decreases luminance flux as temperature rises. If the PWM duty cycle increases faster than the decrease in LED V_F drop, then the LED backlight can go into thermal runaway. The lighting control and management blocks must be capable of measuring LED temperatures and, if they rise above a predetermined value, decrease the duty cycle of all RGB PWM signals to avoid LED thermal runaway, thereby avoiding LED BLU and display failures.

Color management is also important. For W-LED BLUs, only a light sensor is required to maintain overall display brightness, but RGB-LED BLU systems also require a more complicated RGB sensor plus closed color-loop management of the preset or user-selected white

point. Optimal image quality is achieved by using advanced dimming techniques, such as D1 scanning dimming, D2 local or zone dimming, or D3 RGB-based zone or local dimming (see Fig. 2).

To synchronize the LED BLU with a video processor on a frame-by-frame basis, each of the LED BLU's light zones must be synchronously updated with the data addressing of the panel. If the zones and panel data are not precisely synchronized, image quality will be degraded. Optimal synchronization also requires a high-speed connection, such as an SPI bus. Moreover, special communication protocols may be needed to communicate dimming data for every zone in D2 local or zone dimming, and for every RGB string in D3 RGB-based local or zone dimming. The high-speed interface is also

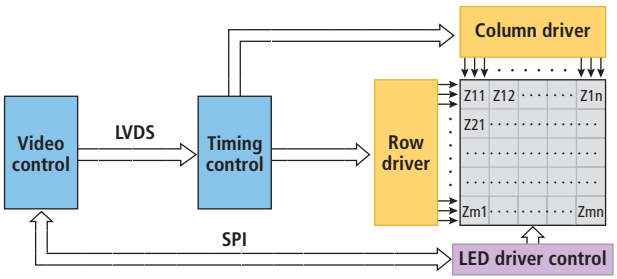

FIG. 2. Advanced design for dimming zones of RGB LEDs.

required for communicating the clock signal and VSYNC data during panel-data synchronization. The bus also must be capable of enabling/disabling information in order to control every zone in D1 scanning dimming mode.

Microsemi has also pioneered a dimming approach called adaptive local dimming, which enables the backlight circuitry to light only the image areas that need to be lit, and dim the black areas. The new approach results in blacker blacks and significantly improved color, contrast, motion sharpness and grey level, plus associated power savings from eliminating unnecessary backlighting.

This backlighting approach is implemented in Microsemi's LX23204 backlight controller, which supports long, high-voltage LED string configurations (up to 300V) for edge-lit backlighting configurations. It's also implemented in the company's LX24132 32-port LED backlight controller and LX23108L 8-port LED driver, which provide scalable, integrated solutions for direct or edge-lit backlight applications in either white LED or RGB LED implementations of flat-panel LCD TV displays.

LCD display designers have a growing array of options for designing LED-backlit panels, and the choice of backlighting architecture and technologies has an enormous impact on cost and display quality, especially in larger screen sizes. An optimal lighting control and management scheme can optimize both power efficiency and image quality, at lower overall system cost. The best picture quality is achieved by using a direct-lit RGB LED BLU implementation of D3 local or zone dimming of individual R, G or B LEDs. However, with the advent of new mega-contrast dimming techniques, it is also possible to achieve outstanding image quality and dynamic contrast with the deepest possible black levels in ultra-thin edge-lit designs.

last word

Solid-state lighting isn't just about decreasing energy consumption

More-efficient, lower-cost lighting could cause people to consume more light in the future, so overall energy consumption may not decrease, says **JEFF TSAO** of **SANDIA NATIONAL LABORATORIES** and his colleagues.

When, in the late 1990s, the idea of solid-state lighting was first articulated, there was a lot of excitement over the possibility that it would enable a reduction in worldwide energy consumption. The simple math was that if the efficiency of solid-state lighting was, say, 4x higher than that of traditional lighting, then you'd decrease the consumption of energy for lighting by the same factor, 4x. And, because the percentage of the world's primary energy consumption that is due to lighting is significant (6.5% or so), the macroeconomic impact would also be significant. This was exciting stuff!

In the late 2000s, though, a number of ideas emerged that caused us to wonder about that simple math. There was the monumental study by Roger Fouquet and Peter Pearson at Imperial College showing how per-capita consumption of light in the United Kingdom had increased massively over the past 300 years. There were theoretical studies indicating that the magnitude of the so-called rebound effect could be pretty significant – the rebound effect is basically what happens when an increase in the efficiency of an energy service leads to a decrease in the cost, and consequently an increase in the consumption, of that service. And of course there was the direct experience of our own semiconductor electronics and optoelectronics community, where increased chip performance and decreased cost always seem to lead to increased market demand for those chips.

So we decided to take a closer look. What we found, amazingly, was that, over the past 300 years or so, a relatively simple relationship connects consumption of light with wealth and cost of light. We had to make a number of assumptions, and there are certainly nuances that deserve more attention, but the bottom line is this: the wealthier people are and the lower their cost of light, the more light they have consumed.

This empirical finding was more than a little disconcerting. If it were to continue to hold in the future, then, seemingly, increases in the efficiency of lighting would decrease the cost of light and would cause people to consume more light in just such an amount as to cause energy consumption to stay the same!

Something wasn't adding up. How could improving the performance of a technology cause us as a human society simply to stand still? What's missing? Well, what's missing, we think, is that we had forgotten that light isn't something, like sleep, that we only want a certain amount of. Light is something that makes us productive and, at least in the past, more light has made us more productive.

So the subtle shift in thinking is one in which solid-state lighting is not just about energy consumption, but about energy consumption and human productivity. On the one hand, if we don't mind a future in which we consume the same or more energy, solid-state lighting – by allowing us to consume more light "for free" – has the potential to greatly increase human productivity. On the other hand, if we do mind such a future, and governments act to reduce energy consumption, solid-state lighting can help mitigate the reduction in human productivity that would otherwise occur. This is just as exciting stuff!

Co-authors JEFF TSAO, RANDY CREIGHTON, MIKE COLTRIN *and* JERRY SIMMONS *are with Sandia National Laboratories, and* HARRY SAUNDERS *is with Decision Processes Incorporated.*

References and acknowledgments

Tsao et al's paper "Solid-state lighting: an energy-economics perspective" was published in Journal of Physics D: Applied Physics vol. 43 no. 35 (http://iopscience.iop.org/0022-3727/43/35/354001).

A New York Times blog on this story provoked a strong response: see http://ideas.blogs.nytimes.com/2010/08/31/are-better-bulbs-a-bright-idea.

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