LED professional

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# Review

LpR

*The leading worldwide authority for LED & OLED lighting technology information*

Sept/Oct 2013 | Issue 39

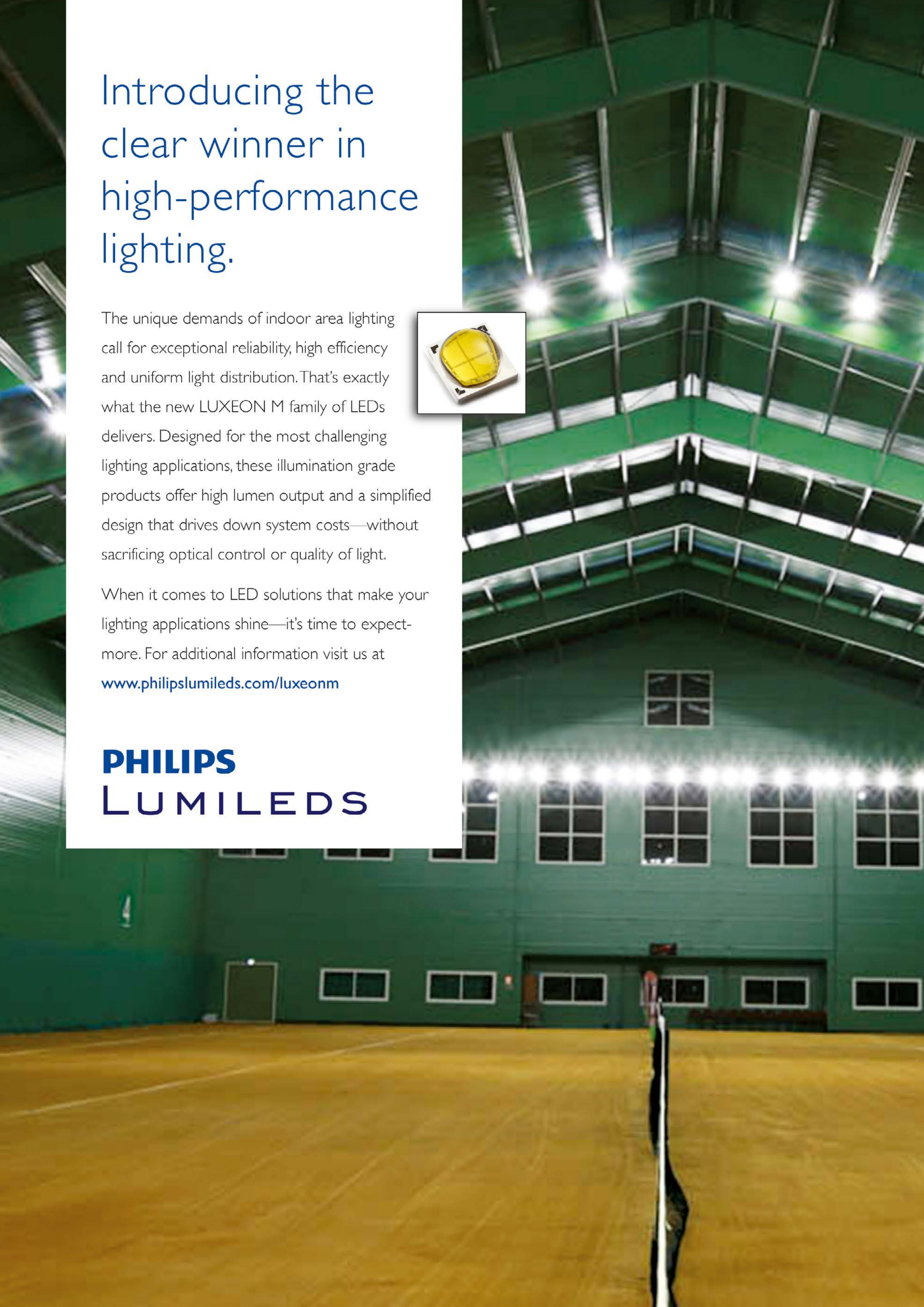
Reliability-Oriented Design

Natural Design for Heat Sinks

Micro- and Nanostructured 3D LED Technologies

Safety Regulations & Production Testing

LpS 2013 ISSUE


Introducing the clear winner in high-performance lighting.
The unique demands of indoor area lighting call for exceptional reliability, high efficiency and uniform light distribution. That's exactly what the new LUXEON M family of LEDs delivers. Designed for the most challenging lighting applications, these illumination grade products offer high lumen output and a simplified design that drives down system costs—without sacrificing optical control or quality of light.
When it comes to LED solutions that make your lighting applications shine—it's time to expect-more. For additional information visit us at
www.philipslumileds.com/luxeonm
PHILIPS
LUMILEDS

# LED Lighting Technologies

It isn't only the general lighting market that is being fundamentally changed by Solid State Lighting technologies; it's the whole lighting industry. Predictions for the next five to seven years are that we'll see more LED/OLED performance increases along with continuous price declines. The challenges of phasing out old technologies and ramping up new technologies are huge. Therefore, profitability is key to survival in this volatile environment.

"Merging" lighting with the fast and innovative semiconductor industry requires new processes, structures, partners, alliances and a new understanding of the lighting sector itself. Restructuring the lighting business to enable potentials for new, environmentally friendly lighting is required to make a substantial contribution to the world's energy situation. New and enhanced technologies are still the major innovation drivers in semiconductor lighting. Technologies are being increasingly merged on a sub-system level while diverse industries are intensifying their collaborations. But the key question remains: "What will the winning approaches be in the years to come?"

In order to help find the answers, the LED professional Symposium and Exhibition, which takes place in Bregenz, Austria every September, summarizes important success factors in the area of lighting. The LpS 2013 will deliver the latest information about state-of-the-art technology and developments within the entire range of topics that Solid State Lighting encompasses. It covers lectures from the following sessions: Light Sources I-IV, LED Future, LED Systems I-II, Driver & Controls I-IV, Optics I-II, Thermal Management I-II and Application I. There will also be six workshops for those that prefer a "hands on" experience and two tech panels where you can join the discussions.

The LpS 2013, Europe's foremost LED and OLED lighting technology event, presents winning technology approaches and introduces you to industry and research leaders who are important for building up business opportunities. The symposium and exhibition are located at the renowned Opera House and James Bond film location in Bregenz, on Lake Constance.

We hope you enjoy this special edition of LED professional Review (LpR) which coincides with the LpS 2013 event.

Yours Sincerely,

Siegfried Luger

Event Organizer - LpS 2013
Publisher - LED professional

# Content



## Advertising Index





Ling Wu

Ling Wu is the president of International SSL Alliance (ISA), and the Secretary-General of China SSL Alliance (CSA). She has been actively involved in all aspects of Solid State Lighting development in China and around the world for more than a decade.

# THE KEY FACTORS TO ACCELERATE SSL APPLICATIONS: FILLING GAPS, CONNECT STAKEHOLDERS & SHARING EXPERIENCES

**Filling the gap between lighting designers and LED manufactures**

In light of the “knowledge / communication gap” existing between the SSL industry and the professional lighting designers, ISA has set up Working Group 6 (WG6) to establish the bridge between the SSL industry and the lighting designers, to ensure that the SSL industry development and products features can be well-recognized and accepted in the lighting design process and specifications. “ISA 2013 Cross-talk Among LED Manufacturers, Lighting designers & Users” were held jointly with PLDA on June 11th, which have identified seven major challenges and possible solutions to:
Glare reduction of LED, ease of dimming, developing interchangeable components, better thermal management, standard range of color temperatures, standardizing light-technical testing and representation of data, as well as how to lower the system price.
This platform will continue to fill the gap between lighting designers and LED manufactures.

**Connect stakeholders to expand municipal SSL applications**

Driven by urbanization and energy saving renovations, SSL municipal application projects have achieved fast development around the globe. However the usually city-based promotion calls for a global platform to gain traction and sharing experiences or best practices.
The ISA Municipal SSL Application Committee (MSAC) will engage all stakeholders to scale up the deployment of SSL products on municipal level. ISA welcomes all to participate the activities in this platform.

**Sharing application experiences worldwide to enable scaling up**

The best way to present the world the best showcases of SSL industry including the best design, reliable products and high quality installation to expand influence, establish positive images, and raise public awareness is an actual project which people can see its performance and professionals can learn its merits.
Global SSL Showcase TOP 100 (TOP100) is a global, open program to identify the best projects showcases that are excellent and extraordinary , which are worth recommending to the public and industry. In 2012, 10 projects had been selected as the first winners of TOP100. Including City of Los Angeles LED conversion project, Light Centre’s project across the whole Africa by Philips etc. TOP100 will continue identifying influential SSL showcases every year.

**Promoting cooperation on SSL Standardization to ensure quality and customer confidence**

The robust and sustainable development of SSL industry hinges on the up-to-date & systematic standardization support, along with the proper labeling, effective reinforcement measures by certification, and harmonized regional or national approaches. With the principle of “Impactful, no overlapping and achievable”, ISA Technical Committee on Standardization (TCS) will bring in global efforts to develop SSL recommendations, specifications or whitepapers in a timely and prioritized approach. So far, three TCS meetings have identified five priority areas, including “Shortening reliability testing time”, “Entry level specifications” as well as “Recycling and green design of SSL fixtures”, etc. More forthcoming results will be published in TCS4 this November. ■

L.W.

# New Powerful Tiny LED from Osram Opto Semiconductor

The Soleriq S 13 shines over a small illuminated surface with 1,500 lm. Osram Opto Semiconductors' high-power Soleriq LED family has a new member: The Soleriq S 13 boasts high brightness from a light-emitting surface measuring just 13.5 mm in diameter and is available in all color temperatures. This Soleriq LED is also designed for use in luminaires subject to high performance requirements. In hotel, restaurant, shop and luxury residential lighting, the Soleriq S 13 – installed in LED luminaires or lamps – replaces high wattage halogen spotlights.


**Osram's Soleriq S 13 chip-on-board LED has a light-emitting surface of 13.5 mm. The technical properties makes Soleriq S 13 the perfect choice for making Zhaga compatible modules**

Technical data for the Soleriq S 13 (Zhaga compatible):

- Housing dimensions: 18 mm x 18 mm
- Light-emitting surface: 13.5 mm
- CCT (in Kelvin): 2,700 to 6,500
- Typ. brightness 1,500 lm
- Typ. efficiency: - 100 lm/W at 3,000 K
- Color rendering index (CRI): min. 80

The new Soleriq S 13 provides outstanding basic lighting, particularly in the professional sector, thanks to its brightness of 1,500 lm and a light-emitting surface of 13.5 mm. Installed in LED luminaires or lamps as a so-called retrofit, it replaces halogen spotlights with high wattages. "The S 13 is predestined for the hospitality and home lighting sector, because, in addition to its high brightness, it covers all color temperatures. What is more, the color rendering index for all color temperatures is over 80. As a result, the S 13 significantly expands the application portfolio of the Soleriq LED family, whose existing E 30 and E 45 versions previously were designed for downlights," explains Andreas Vogler, Product Manager at Osram Opto Semiconductors.

Uniform Color and light appearance:
Like the E 30 and E 45, the Soleriq S 13 greatly simplifies luminaire design, because thanks to its excellent brightness, only one component needs to be installed in a luminaire instead of several. The individual chips are very closely arranged and all located under a conversion layer (chip-on-board), giving the impression of a homogeneous light emitting surface and ensuring a uniform color and light appearance. For even better homogeneity, the chips are arranged in a circle under the conversion layer. This greatly simplifies the coupling of the LEDs into external, light-guiding optics. The light generated can be used with much lower optical losses, which in turn makes the LED lamps and luminaires more efficient. Typical LED benefits, such as high energy efficiency, long lamp life and the associated minimal maintenance costs, also are evident in downlights fitted with a Soleriq S 13.

Simple installation with no SMT soldering (Surface Mount Technology):
This high-power light source is relatively simple to work with. Unlike other commercially available high-power LEDs, no SMT soldering is necessary to mount the Soleriq S 13; glue, screws or solderless connectors do the job. Although the connecting wires can still be joined by simple manual soldering, and then glued or screwed to the heat sink, the simpler option by far is to use a solderless connector that takes care of both the electrical contact and mechanical mounting. It eliminates the need for soldering; the connecting wires need only be inserted in the terminals provided. ■

# Luxeon 3535 2D Reduces LED Count in Retrofit Lamps

Luxeon 3535 2D, which combines two LED chips in a package to enable reduction in LED count and cost of designing retrofit lamps, consumer downlights and diffuse industrial lamps. Best-in-class efficacy of 140 lm/W is achieved for cool white light at 4000 K and minimum 80 CRI.

"This is an exciting breakthrough, because lighting designers can take advantage of a high lumen package with high efficacy while using significantly fewer chips per fixture," said Rahul Bammi, VP of Product Management at Philips Lumileds.

"For example, a 50 W PAR20 lamp can be achieved using only 4 LEDs. Alternatively, a 40 W A19 lamp that previously required 14 LEDs can now be created using only 6."

**Philips Lumileds' new LUXEON 3535 2D has the highest efficiency in its class**

The new mid-power LEDs are offered across a full spectrum of correlated color temperatures (2700 K-6500 K) with a minimum CRI of 80. Versions with CRI 70 for outdoor applications and CRI 90 for high end indoor applications are planned for future release.

The Luxeon 3535 2D operates at 0.5 – 1 W, delivering up to 130 lumen in the compact 3535 form factor. Rated at 100 mA, the Luxeon 3535 2D can be driven up to a maximum of 200 mA. The Luxeon 3535 2D supports Energy Star® certification requirements up to 25,000 hours at 85°C and 150 mA. ■

# Seoul Semiconductor Announces New Cost Effective and Efficient Mid-Power LEDs

Seoul Semiconductor, a global LED manufacturer, has announced two new mid-power packaged LED lighting products, the 5630C and the 3030. These packaged LEDs have been improved dramatically in terms of luminance efficacy (lm/W) and cost efficiency (lm/$). The 5630 mid-power packaged LED efficacy is now 180 lm/W which is world class performance for solid state lighting. The 3030 mid-power LED reaches cost points 50% lower than existing high-power packaged LEDs.

The 5630 package is the world's best performance in light output with 180 lm/W efficacy and is an extension of the mid-power LED lighting family that Seoul Semiconductor released as one of the first mid-power LEDs in the world for solid state lighting products.

When it was released, the performance was better than existing high-power packaged LEDs. In the past 2 years, it became the best selling item among Seoul's product portfolio. The new 5630C is targeting the high growth segment of LED lighting, including bulbs, tubes and panel lights in the US, Japan, and Europe.

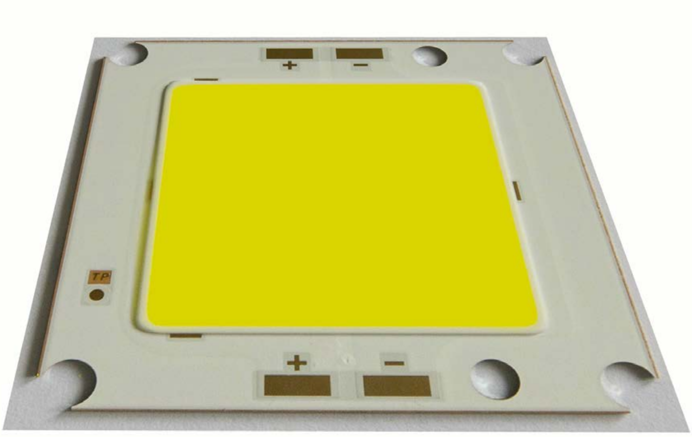
**While Seoul Semiconductor's 5630 packaged LED (left) offers 180 lm/W which is world class performance, the 3030 packaged LED targets a cost point 50% lower than existing high-power packaged LEDs**

The new 3030 LED being introduced extends the Seoul mid-power offering up to the high-power one watt range by enhancing both the LED chip and package in terms of heat resistance. Even though traditional 3030 packaged LEDs were mid-power, the new versions can be used in high power applications with the additional benefit of reducing costs by up to 50%.

Marten Willemsen, Vice President of Marketing for Seoul Semiconductor, said, "The 3030 and 5630 packages are LED products which focus on both price competitiveness (lm/$) and luminance efficiency (lm/W). We have already sold billions of pieces in China, the USA, and Europe for various LED lighting products." He added, "If you use these two LEDs properly, you can chase two rabbits at the same time in terms of 'lm/W' and 'lm/$' which most lighting designers consider the most important factors." ■

# Lighten Unveils Lightan IV HV COB Emitter Series

Lighten Corp., leading LED COB Emitter provider, launches its latest Lightan IV HV COB LED Emitter. This series provides not only low thermal resistance, high lumen output efficacy, anti-vulcanization emitters but also dedicated design for Philips Xitanium high voltage power series with high transfer efficiency and best quality.



**Lighten's new Lightan IV COB Emitter are optimized for Philips Xitanium high voltage power series drivers**

Through special layout and unique material, Lightan IV HV COB series can stand high voltage while other metal substrates can't overcome this problem. With Philips Xitanium series power, Lightan IV HV COB series can increase 5% power transfer efficiency (i.e. 5% light output efficacy) and make high power lamp application in line with different requirements more easily.

Critical dimensions like the emitting area and tooling hole of Lightan IV HV COB series is identical to the most popular molding leadframe package in Asia. Lamp manufacturers can replace emitter / power directly to get more light output efficacy with more confidence based on Lighten's high quality product and Philips power.

Lightan IV HV COB series provide different High CRI (70, 80, 90) options for customers. In 2013 Lighten Corp is keeping its pace to provide high power, high efficiency, the best quality, energy-saving COB emitters for customers' various needs. ■

# TALEXXengine STARK SLE Generation 3

Only nine months after the 2nd generation, Tridonic is now launching the 3rd generation of the TALEXXengine STARK SLE LED light engine – more cost-effective and more efficient. Generation 3 makes for impressive reading: up to 80% higher luminous flux, greater efficiency under real-life conditions (up to 125 lm/W at 4000 K) and better hot lumen efficiency (up to Tp = 85°C). Even after 50,000 hours of operation the 3rd generation achieves a life of up to L90. At the same time the modules are matched to the new ECO and TOP series of TALEXXconverters and together constitute an optimum system.

**Up to 125 lm/W at 4000 K, better hot lumen efficiency, and L90 of 50,000 hours are key improvements of TALEXXengine STARK SLE's 3rd generation**

With the new LED module, Tridonic is presenting itself as a competent system supplier for professional lighting solutions based on chip-on-board (COB) light sources. Thanks to a new COB design with improved thermal properties, more efficient LED chips and perfect matching with the appropriate converters, the Classic, Select and Minimodules achieve even greater efficiency at lower costs. Up to 4800 lumen can now be emitted from an LES 19 (Light Emitting Surface). There is also a new operating mode for the Classic and Select modules, known as Best LED Operation (BLO). This ensures an ideal balance between efficiency, lifetime and costs. The lumen package is automatically configured when the LED module is connected to the converter. The luminous flux remains constant at all times, even if the color temperature changes.

The 3rd generation of the TALEXXengine STARK SLE light engine yet offers high quality of light of up to CRI 90 with very small color tolerances corresponding to MacAdam 3 and even MacAdam 2 as an option. Differences in color are therefore barely perceptible so the light is extremely uniform. The reproducible white light is available in the standardized color temperatures of 3000 and 4000 K. For excellent color rendering CRI > 90 is now available also for the MINI module.

Chip-on-Board technology allows optimum thermal management for the LED modules so efficient operation at temperatures of up to 85°C is possible. The associated smaller form factor gives luminaire developers even greater freedom of design, especially for creating compact fittings.

The converters for the LED modules are available in surface mounted and in-built versions. They offer various interfaces for precise trouble-free control, including switchDIM, DALI and DSI. Integrated terminals on the LED modules – a joint development with the subsidiary Tridonic connection technology – ensure simple wiring with standard luminaire cable, reducing installation time and costs.

In addition to the Classic, Select and Mini units, the TALEXXengine STARK SLE series includes the Food and Premium modules, with Premium offering tunable white along the Planckian curve from 2700 to 6500 K.

The properties of the new generation will benefit customers who use the components of older versions because the system is downward compatible with identical mechanical and optical interfaces, and therefore represents a sound investment for the future. ■

# Genesis Photonics Launches 3D COB

Genesis Photonics Inc. (GPI) 3D Chip On Board (COB) successfully integrates blue LED components with a variety of remote phosphors. Compared to the average COB product, 3D COB has better lighting quality and has the advantages of greatly reducing lighting system costs, and expanding the market for new lighting applications. Moreover, using a combination of high powered blue LED components with patented remote phosphor offers lighting fixture manufacturers additional patent protection.


**Successful application of Genesis Photonics 3D COB solution in candle lamps (1), bulbs (2), downlights (3), and bay lights (4)**

GPI's 3D COB integrated solution can be used with dimensional lighting or plane lighting remote phosphor solutions. Compared to single or group LED packages, where phosphor is placed very close to the die and receives near range concentrated light source stimulation, the remote phosphor used in 3D COB are is located further away from the die and excited by long range light source. The advantages provided by such an arrangement include excellent lumen maintenance, small differences in hot-cold factor, and slight color shifts. In addition, by applying remote phosphors in GP's high luminous efficacy Match LED, it is also able to get improved color uniformity and diverse color temperature options. For luminarie manufacturers, these technological advantages open up a lot of opportunities for luminaire manufacturers to create more flexible light fixture designs.

Standard specifications can cause inventory risks when client demand changes. GPI's 3D COB's core light source employs the patented blue light Match LED component, a technology developed by the company. The component is constructed on the foundation of AT chips, and includes the following features: wire-bond free, compact arrangement, low thermal resistance, and high light efficiency. From the AT die, Match LED component, to the 3D COB light source solution, GPI has been cooperating with top international phosphor brands, to provide sophisticated light efficiency levels and patent protection.
This also helped improve luminaries' clients' opportunities of entering the global market. Currently, GPI's 3D COB is being introduced to lighting manufacturers in the U.S., Japan, Europe and China. ■

# Cree Improves LMH2 LED Module to Obsolete 70-W CMH Lamps

Cree introduces the new 4000-lumen LMH2 that delivers the industry's highest-performance LED module. The barrier-breaking module produces the same or better quality light as 70-watt ceramic metal halide (CMH) lamps while consuming half the power and lasting three times longer - a first in the LED industry.

"The new 4000-lumen LMH2 LED Module is an ideal LED light source to replace 70-W ceramic metal halide in many lighting applications," said Quinten van de Vrie, director, LEDs Progress. "We can provide our customers the same light quality and brightness required for their spaces using just half the power of our competitors still using CMH. Working with Cree gives us a significant performance advantage over our competitors."


**Cree's updated LMH2 series is also available with flat dome lens. Drivers and optional heat sinks are available on request**

The aesthetically pleasing LMH2 LED module lets lighting manufacturers quickly and easily add LED options to their existing lighting portfolio - addressing different applications with lumen levels ranging from 650 to 4000 lumens with just one set of tooling and one optical design.

"The new LMH2 LED module allows us to quickly expand our line of LED lighting without making any changes to the beautiful vintage housing that we're known for," said Bryan Scott, owner, Barn Light Electric. "Cree's 4000-lumens LMH2 LED module will allow us to replace ceramic metal halide and CFL, which our commercial customers are requesting. Now customers that want to light big spaces with high ceilings have brighter options of the same beautiful, energy-efficient light in the style and charm of vintage-style barn light fixtures."

The new module family delivers up to 108 LPW system efficacy with a CRI greater than 90 in all available CCTs. The high-performance LMH2 module family enables manufacturers to leverage one product platform to create an entire product portfolio - delivering the investment protection necessary to quickly and cost effectively address more lighting applications.

"We are excited that Cree is expanding the LMH2 LED Module family because they provide LED lighting solutions with low design risk," said Mike Wang, vice president, lighting engineering, Edison Price Lighting. "The LMH2 LED module delivers all the best features of lighting technology - light output, efficacy, quality of light and long lifetime - in a stable format. We know we're getting the best of Cree's technology, allowing us to focus on the luminaire design."

The LMH2 module family is available in a range of lumen (850, 1250, 2000, 3000, and 4000), color temperatures (2700 K, 3000 K, 3500 K and 4000 K) and driver options, including digital-addressable lighting interface (DALI) and DALI® touch-dimming driver options, enabling lighting manufacturers to expand their portfolio quickly and easily. Designed for 50,000 hours of operation and dimmable to five percent, the LMH2 module comes with Cree's industry-leading five-year warranty. Luminaire makers seeking ENERGY STAR® qualification will have access to specification and performance data, including LM-80 reports, which can speed regulatory approvals. ■

## Xicato Introduces Its Vibrant Series™ of LED Modules

Xicato, a leading provider of LED modules for retail, hospitality and specialty lighting environments, introduced its Vibrant Series LED modules. Light from the Vibrant Series is spectrally engineered by Xicato's color scientists to make colors appear richer and more vivid and to bring out textures and depth of materials like never before. The design of the light is based on original research conducted in the lighting laboratory at the Instituut Lichtontwerpen in Amsterdam and designed by Colette Knight, Ph.D., an independent lighting application specifier and researcher.

**In addition to the Standard Series and Artist Series, Xicato's light portfolio now includes the new Vibrant Series with a new light emission spectrum that makes whites, blues and reds in particular appear richer and more vibrant**

Technical Specifications:
- Module type: XSM
- Flux: 3000 lumens
- CCT: 3000 K
- GAIBB: 111
- CRI: ≥80
- Efficacy: 67 lm/W
- Compatibility: Direct drop-in for Standard or Artist Series XSM modules

Color scientists at Xicato were able to use the feedback of more than 60 subjects to design a new light emission spectrum that makes whites, blues and reds in particular appear richer and more vibrant and to add visual depth to textures like denim, leather or lace. The research, conducted with over 40 top lighting designers and 20 shoppers, demonstrated that in many cases, people have a significant preference for light that makes an object's color appear more brilliant. To determine each viewers color preference, they were presented with mock displays and environments in which color rendering and the gamut area of the colors rendered were varied. Color temperature remained constant at 3000 K which is common for lighting in shops, galleries and restaurants.

LedLink
Linking LEDs to The Real World

# STREET LIGHTING

Asymmetrical

## Brightness


Tape available

**LL01LU-AEV50150L02**
**LxWxH(mm)** 18 x 12.5 x 6.3
**FWHM** 50°x150°
Cree XP-G2
Lumileds Rebel ES
Nichia NVS19B
Osram Oslon Square


Tape available

**LL01ZZ-AGX45155L02**
**LxWxH(mm)** 18 x 12.5 x 7
**FWHM** 45°x155°
Cree XP-G2
Lumileds Rebel, Rebel ES
Nichia NCS19, NVS19


Tape available

**LL01CR-APM80150L02**
**LxWxH(mm)** 18 x 12.5 x 6.94
**FWHM** 80°x150°
Cree XT-E
Lumileds Rebel
Nichia NVS19

**LL01LU-AGV80150L02**
**LxWxH(mm)** 32 x 18.5 x 9.5
**FWHM** 80°x150°
Cree MKR
Lumileds Luxeon M
Nichia 383

## Illuminance

**LL01CR-OW70130L02**
**LxWxH(mm)** 17.4x 12.75 x 7.2
**FWHM** 70°x130°
Cree XB-D, XP-G2, XT-E, XML
LGIT Ceramic 3535
Lumileds Rebel, Luxeon T
Nichia NCS19, NVS19, NVS19B, 383, 757
Osram Oslon SSL 80 / Square


Tape available

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

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

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

# AREA LIGHTING

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


LL01ZZ-EXxxL06-M2
LL01LU-EXxxL06-M2
Tape available

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

## DF/BDF/AAF Series


Tape available

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

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

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

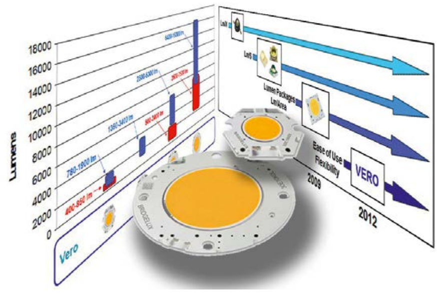
With a clear understanding of viewer and shopper preferences, Xicato's color scientists designed a new spectral power distribution that created the preferred vibrancy effect without making the surrounding environment feel cooler or uncomfortable which is often the result of simply adding additional red and green LEDs to an existing light source.
The task required re-engineering the color gamut rendered by the light source. Managing color rendering and the associated color gamut in combination is key to creating light that feels right and looks alive.
By selecting and tuning the phosphors and LEDs in a similar fashion to the Standard and Artist Series, Xicato was able to retain an identical form factor, optical interface and electronic specification as its existing portfolio and produce the new vibrant light with its unique spectrum.

"The emotional and experiential impact of vibrant light is undeniable," said Joanna Brace, VP of Marketing and Business Development at Xicato. "Throughout Europe and North America viewer response has been tremendous and as a result, a number of retail installations are underway now. Vibrant Series gives the market a powerful tool for differentiating their spaces and creating novel user experiences that can't be had online."

"This is the only LED light that we have evaluated that brings out the brilliance and texture of objects, and does so without casting a cool or uncomfortable feeling to the room," said Werner Jost, Managing Director at Optelma France, one of the many companies already developing solutions that use the Vibrant Series. ■

# Bridgelux Improves Efficacy and Color Uniformity of Their Vero Series

Bridgelux, a leading developer and manufacturer of LED lighting technologies and solutions, announced that its recently released Vero™ Series of LED array products are now shipping with industry leading performance efficacy (122 lm/W nominal, 110 lm/W minimum average). This erformance enhancement delivers energy savings of approximately 11% over the prior product generation and provides a significantly accelerated return on investment. Further, the Vero Series arrays are now available with 2SDCM MacAdam and 3 SDCM options – raising the industry bar in color control precision and uniformity.




**Bridgelux's advanced Vero array LEDs are the perfect basis for future developments**

Features:

- Lumen output performance ranges from 240 to 16,400 lumens
- CCT options from 2700 K to 5000 K
- CRI options include 70, 80, 90, and 97 CRI Décor™ products
- 3SDCM standard for 2700 K – 4000 K CCT with 2SDCM options now available
- Reliable operation at up to 2x rated drive current
- Radial die pattern improves lumen density and beam control
- Thermally isolated solder pads reduce manufacturing time and complexity
- Solder-less connector port enables plug & play connectivity and field upgradability
- Top side product marking and 2D bar code improve inventory management

The featured 122 lm/W efficacy is an average performance across all form factors in the Bridgelux Vero Array Series based on 3000 K 80 CRI configurations driven at nominal currents. With some Vero configurations driven at lower currents, users can readily achieve efficacies up to 140 lm/W. The Vero arrays also deliver industry leading average minimums of 110 lm/W and provide designers with best-in-class design and manufacturability flexibility.

The Vero platform enables plug & play connectivity for lighting manufacturers, enabling leading solid state lighting product performance capabilities while streamlining production processes for lighting manufacturers. These capabilities lead to shorter product development times, lower inventory requirements, reduced costs and more light with less energy.

Beyond saving energy, the Bridgelux Vero Series of LED arrays delivers another industry first by providing customers with a standard option of choosing either 2SDCM or 3SDCM MacAdam color control.
Having more precise color control options improves the quality of light by providing greater consistency and uniformity between adjacent light sources. This exciting advancement in color control options with the Vero Array Series enables clean and consistent lighting installations with both high quality color rendering and appearance.
The Vero Series also exceeds California Energy Commission R9 requirements for luminaires and lamps.

Vero arrays are compatible with a wide variety of standard drivers (350 mA increments) and optical components, providing manufacturers with greater flexibility and a wide range of options, shortening product development times, lowering inventory requirements and reducing costs. Electrical connections can be established with thermally isolated solder pads or by using a solder-less on-board connector port. The solder free connector port simplifies manufacturing processes, reduces production time/cost, and eliminates the potential for solder failures.

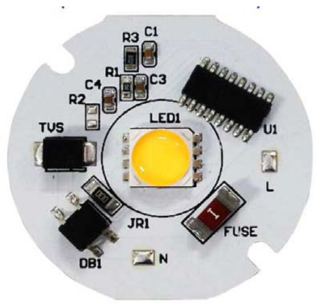
"The Vero arrays have been one of our most successful product offerings in our ten year history," said Aaron Merrill, Director, Product Line Management of Bridgelux. "Solid state lighting is making huge gains in virtually every segment and geography, but we must continue to find ways to drive down total system costs, while increasing performance. Vero arrays will play an instrumental role in bringing new methodologies and technologies to the solid state lighting market, and provide a platform for the convergence of technologies required for smart lighting." ■

# ProLight Opto Launches New Driver on Board Series

ProLight DOB (Driver on Board) series are designed to be driven directly off of AC 110 V without converters. It is a brilliant solution for lighting designs with limited space.

ProLight Opto thrives on providing customers with design-friendly products, and the latest DOB series will be no different. At 6 W and 7 W, ProLight offers the best-in-class replacement for incandescent bulbs. 15 W is the perfect solution for down lights.




**Prolight's DOB series integrates a complete lighting solution with an integrated driver design that eliminates lifetime critical components without compromising performance**

The converter and driver are the major factors on the lifetime limitation in LED lighting products. ProLight's DOB series have embedded the driver IC, various components and emitter altogether on a single ALPCB. Designed to be driven directly off of AC 110 V without converters, ProLight's DOB series are able to achieve higher efficiency and better lifetime. The compact design of ProLight's DOBs looks to help maximize the creativities of lighting designers.

## Edison Opto Unveils Direct-Lit Light Bar

The Taiwan-based high power LED manufacturer, Edison Opto, has released a direct-lit backlight / lighting module. Using the high efficacy component - ET-3528 as light source with secondary optical lens, the emitting angle of light bar can be widened up to 150°, which expands the illumination range. In addition, thanks to the excellent light uniformity, naked eyes can't see the light source even when the light bar is mounted in an ultra-thin light box. The direct-lit light bar is suitable as the light sources of panel lights, advertising light box and refrigerated display case.

**Edison Opto's new ET-3528 direct-lit light bar is suitable as the light sources of panel lights**

Specification:

| | |
|---|---|
| LED Quantity: | 7 pcs/light bar |
| Dimension: | 520 mm x 17 mm x 1 mm |
| Power: | 7 W |
| Brightness: | 700 lm / 670 lm / 640 lm |
| CCT: | 6000 K / 4000 K / 3000 K |
| CRI: | 80 |
| Efficacy: | 100 lm/W |

Compared with the side-lit LED TVs which require light guide plates, direct-lit LED TVs do not need such components. Moreover, LED efficacy has been increasing so that the quantity of LEDs per TV can be reduced. Edison Opto's direct-lit light bar has the advantages of high lm/$ and cost saving which are superior to side-lit LED module.

Direct-lit light bar applied in advertising light box and panel light can save (up to) 30% power consumption. Whether as a lighting application or backlight, the direct-lit light bar can help luminaires and TVs to become lighter and thinner. The light bar is a versatile, efficient and energy saving solution for lighting and backlight.

## LEDiL's Veronica Family Protect LEDs from Harsh Environments

LEDiL's new Veronica family represents an innovative way of designing TIR optics. A single molded piece that triples as an optical element, structural holder and a sealing surface.

**With different light distribution options, LEDiLs new Veronica also provides a sealing surface to protect LEDs**

Applications:

- Outdoor architectural lighting
- Facade lighting
- Display and billboard lighting

Key Features:

- PX8 suited
- Tape protects the LED from potting agent during the installation
- The round, slightly larger version has optimal optical performance but needs to be potted using potting resins with higher viscosity
- The square version has the same footprint as the Strada-SQ lenses, making it more versatile to use
- Precision-molded from high grade optical PMMA
- UL94 HB rated material with a wide operating temperature range
- ROHS and REACH compliant
- Mounting with adhesive tape or glue
- Very low-viscosity potting resins can be used

Veronica family members features:

C13528_Veronica-RS:

- Typical[1] FWHM ~10°
- Diameter 26 mm
- Height 12.2 mm

C13529_Veronica-O:

- Typical[1] FWHM ~55+14°
- Diameter 26 mm
- Height 12.2 mm

CA13724 Veronica-SQ-RS / C13727 Veronica-SQ-RS:

- Typical[1] FWHM ~11°
- Diameter 22.5 x 22.5 mm
- Height 12.2 mm

CA13726 Veronica-SQ-O / C13728 Veronica-SQ-O:

- Typical[1] FWHM ~56+12°
- Diameter 22.5 x 22.5 mm
- Height 12.2 mm

Make Veronica your weapon of choice for challenging environments and outdoor applications. Special attention paid to ensure easy ingress protection – making Veronica suitable for applications requiring IP ratings up to IPX8. Two lens types with real spot and oval beam patterns already exist, and more are on the way.

Veronica is available in two form factors: the round, slightly larger version is optimized for optical performance whereas the square Veronica-SQ has adhesive tape for easy installation and a slightly smaller footprint. ■

# Khatod's Latest Lenses offer 3° Beam Angle

Khatod's Ultra Narrow Punch Beam Lenses are high efficiency TIR lenses, designed for use with the most popular existing LEDs of latest generation. They collimate the light coming from the LED into a perfect ultra-narrow beam that maximizes the usable lumens in the target area, excellent for many new lighting applications requiring an enhanced focal depth. The new lenses are available in 3 different diameters - 50 mm, 46.8 mm and 35 mm.


**Optical project, molding, tooling realization, and production of Khatod's Ultra Narrow Punch Beam Lenses are 100% in house**

General Characteristics & Features:

- Lens material : Optical Grade PMMA
- FWHM = 3.5° for 1 $mm^2$ chip area LEDs
- CBCP (Center Beam Candle Power) = 150 cd/lm
- Smallest Shape Factor Lens (Diameter × FWHM / Chip Size
- LED Chip Projection on target totally eliminated
- Clean Spot, Efficiency > 89%
- Perfect uniform flux
- Easy fixing onto the PCB: 3 Pins provided for precise and robust mounting
- Available in 3 different diameters:
  - PL1672UN : Ø = 35.0 mm, H = 21 mm
  - PL1675UN : Ø = 50.0 mm, H = 21 mm
  - PL1738UN : Ø = 46.8 mm, H = 21 mm

Main Applications:

- Punch Beam
- Spot light
- Entertainment lighting
- Architectural lighting
- Wall washer
- Stage lighting
- Decorative lighting
- Shop windows, halls & entrances
- Flashlights
- Bicycle lights
- Headlamps

The Ultra Narrow Lenses from Khatod are TIR (Total Internal Reflection) high efficiency lenses designed for use with the most popular existing LEDs references of latest generation. The high flux density and high emitting potential produced by these LEDs require lenses able to deliver superior beam control.

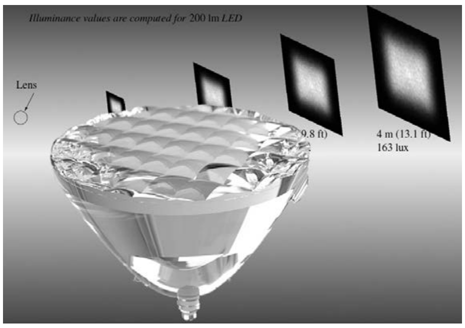
Ultra Narrow Punch Beam Lenses collimate the light coming from the LED source into a perfect ultra-narrow beam that maximizes the usable lumens in the target area. It provides the best solution for many new lighting applications requiring an enhanced focal depth. These newest optics projects a smooth light beam of uniform intensity that minimizes glare and maximizes the lighting efficiency, making them ideally suited to any application where a high efficient punch beam is requested.

The Ultra Narrow Lenses from Khatod are the solution for your applications requiring an ultra-narrow punch beam. Unavailable on the market up to now, Khatod is now delivering the unique 3° beam angle lens, the tightest beam of light performed by a secondary optic for SSL applications. The excellent optics is able to sharply define the spot of light coming from the LED source.

The mounting onto the LED is easy and immediate: 3 pins on the lens bottom allow a precise and robust mounting. ■

# Khatod Announces Clean Rectangular Beam Lens

The newest Single Lenses from Khatod, able to perform a superior Clean Rectangular Beam, are high efficiency lenses designed for use with the most popular existing LEDs references of the latest generation.




**Khatod's new Clean Rectangular Beam Lens is useful for different applications and intended to provide a high quality illumination and not for focusing a single individual point**

General Characteristics:

- Single Lenses performing Rectangular Beam Angle for Common LEDs
- Beam Angle for Common LEDs
- Invariant performance for a wide range of LEDs
- Lens material: Optical Grade PMMA

Features:

- Beam size at 1 m - A4 paper sheet - (300×200 $mm^2$, 12×8 $inch^2$)
- Excellent Uniformity > 85%
- Clean Spot
- Efficiency > 89%
- Perfect uniform flux
- Easy fixing onto the PCB: 3 Pins provided for precise and robust mounting
- Currently available in Ø 35.0 mm diameter.
- On request, also Ø 50.0 & Ø 46.8 mm

Typical Applications:

- Museum lighting
- Desk lamps
- Entertainment lighting
- Architectural lighting
- Stage lighting
- Decorative lighting
- Shop windows, halls & entrances
- Inspection lines
- Flashlights

Most of lenses for LED applications in current use perform output beams with circular or elliptical profiles. The light distribution as well as the intensity they produce is mostly suitable for many applications in which a small spot is focused by the light beam. However, a uniform intensity distribution focused to a wider and not circular pattern, often referred to as a “flat-top”, is increasingly required in many different uses.

This rectangular spot is used essentially for illumination and not for focusing a single individual point. For this reason, the illumination needs to be uniform, and any point in the rectangular light pattern needs to have the same brightness, regardless of where it is located in the illuminated field. Thanks to Khatod's most advanced optical technology, this new series of optics is able to produce such a perfect rectangular beam.

These characteristics cover a wide range of applications from lighting in a museum to desk lamps or inspection lines.

Khatod Rectangular Beam Lens is currently available in 35 mm diameter with 3 mounting pins on the lens bottom. ■

## 300° T8 & T5 LED Replacement Tube Covers from BICOM

Bicom Optics is one of the first enterprises that became involved in optical studies, lens design and product development of the LED lens. Recently, Bicom Optics has successfully developed a T8 and T5 tube. - The light angle of traditional fluorescent tubes is 360°.

**Bicom's LED tubes offer 300° light distribution which is almost the same as that of traditional fluorescent tubes**

Due to the LED light properties, the general LED tube's light angle is 120°. In order to fully replace traditional light, Bicom Optics continues to make breakthroughs in the LED tube light emitting angle.

We adopt the whole PC tube technology that can achieve a maximum of 300°. This means that it can satisfy customer's requirements of a large angle with better illumination distribution.

We adopt integration cooling technology to reduce the cooling channels. This means the LED chip can stay in a lower position, which enlarges the LED luminous surface and the PC tube wall distance and then expands the light angle.

In addition, the whole PC tube is made of high light transmittance diffusion PC material, with up to 85% efficiency. This kind of material not only achieves a more uniform light effect, it also makes light angle increases. ■

## LED Driver Delivers High Performance and Lower Costs

Dialog Semiconductor plc, a provider of highly integrated power management, audio, AC/DC and short-range wireless technologies, announced a new solid state lighting (SSL) LED driver that integrates boost and flyback converters into a single IC to reduce the bill of material (BOM) costs and simplify the design, compared to conventional two-stage driver approaches, while delivering exceptional performance.


**One special feature of Dialog's new driver IC is a controlled built-in over-temperature protection and derating function instead of a simple thermal shutdown function**

iW3623 Key Features:

- Output power: 3 W to 45 W
- Universal input range: 100 – 277 VAC
- High power factor (PF) >0.95
- Low total harmonic distortion (THD) <10%
- Flickerless technology eliminates LED flicker with <5% 100 Hz – 120 Hz output current ripple
- Integrated boost and flyback converters, primary-side control: reduce solution size, lower BOM cost, increase reliability
- NTC-based LED over-temperature protection (OTP) and derating
- Meets global standards, including European Union IEC61000-3-2(1) requirement
- Compatible with Zhaga(2) hot-plug LED module for LED light interchangeability

The new iW3623 was developed by Dialog's Power Conversion Business Group, formerly iWatt Inc., acquired in July 2013 and delivering on Dialog's product portfolio diversification strategy to expand into the digital power management market space.

The iW3623 offers a universal 100 VAC to 277 VAC input range and output power up to 45 W. It integrates a boost controller for power factor correction (PFC) and a flyback converter for LED current regulation, while enabling high PF >0.95 and low total harmonic distortion (THD) of <10%. Dialog's patented Flickerless™ design achieves a near-zero 100 to 120 Hz output ripple and the built-in over-temperature protection (OTP) and derating enables lighting designers to deliver a predictable, reliable bulb operating life.

The rich combination of integrated features makes the iW3623 an ideal solution for a wide range of non-dimmable, commercial SSL downlight, PAR, T8, and flat panel ceiling lamp applications.

The iW3623 provides additional BOM savings by using Dialog's patented PrimAccurate™ primary-side control technology that eliminates the need for a secondary-side regulator and optical feedback isolator. It also allows FETs to be replaced with lower cost bipolar junction transistors (BJTs). While using BJT switches lowers the total solution cost, achieving high conversion efficiency can be a challenge. The iW3623 solves this by using quasi-resonant mode switching for both the boost and flyback stages and dynamic base current to optimize conversion efficiency and minimize EMI. Additionally, Dialog's EZ-EMI® technology simplifies EMI filtering to further minimize the external component count.

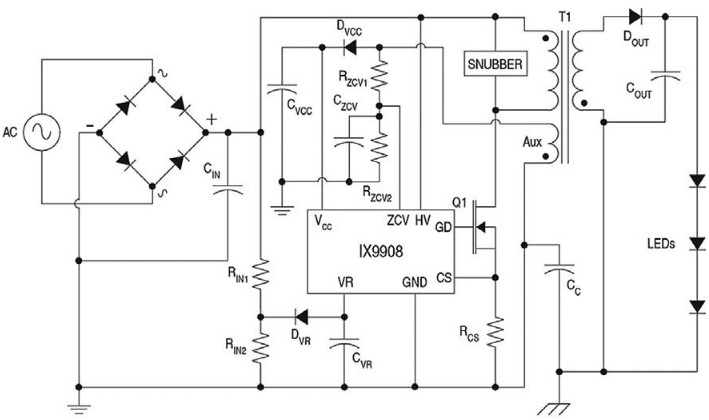
Most power ICs are designed with a thermal shutdown feature, which simply shuts the IC down in high temperature environments. This protects the IC, but not the LED driver circuit. The iW3623 includes a robust, built-in over-temperature protection and derating function that actually monitors the temperature inside the sealed SSL bulb. The OTP feature is configured via an NTC resistor. When thermal conditions in the bulb reach the set temperature, the iW3623 automatically and incrementally reduces the current drive to the LEDs. This lowers the power dissipation, results in cooler operation, and ensures the temperature rating of the electrolytic capacitors in the system is not exceeded. Derating allows the capacitors to operate within the maximum lifetime of the SSL bulb and results in a predictable bulb operating life. The derating of the current drive results in negligible light reduction, so users will likely not experience any visible changes in light output. In extreme temperature situations, the iW3623 will shut down the current drive to the LEDs to prevent safety and fire risks.

Additional, iW3623 safety features include LED open/short circuit, single fault, over-current, current sense resistor short-circuit, input over-voltage, brown-out and AC line over-voltage/frequency protections. During output over-voltage conditions, the iW3623 goes into an extended discharge mode, while maintaining a quick recovery, allowing support for hot-plug LED modules without causing dangerously high output voltages. ■

## IXYS Announces Highly Efficient New High Voltage LED Driver

IXYS Integrated Circuits Division, a wholly owned subsidiary of IXYS Corp., announced the immediate availability of the IX9908 High Voltage, Dimmable LED Driver with PFC Control The IX9908 is a quasi-resonant controller that is optimized for dimmable off-line LED lighting applications. The IX9908 incorporates a precise pulse-width modulation (PWM) circuit and cycle-by-cycle peak current control to support flicker-free, phase-cut dimming with a high power factor correction (>98%). Utilizing IXYS ICD's high voltage IC expertise, the IX9908 is rated to 600 V, making it suitable for both 120 V and 240 V offline applications.

Features:
- Single Stage, Primary Control with PFC and Dimming Features
- >90% Efficiency
- Power Factor >98%
- Wide Operating Voltage Range: Up to 600 V
- Digital Soft-Start
- Cycle-by-Cycle Peak Current Control Applications
- Incandescent Bulb Replacement
- Solid State Lighting
- Industrial and Commercial Lighting




**Example application schematic with the IX9908 that allows for the realization of greater than 90% efficiency**

"It's a significant extension to the lineup of our LED driver products, we offer now a wide range of products for the energy efficient LED lighting industry. Coupled with our wireless MCU-based lighting control applications, with the ZILOG designs, and the IXYS power semiconductors, we again offer our customer the whole solution. Our HVIC designs using our proven rugged technology outperform the competition especially when it comes to higher temperature operation and immunity to latch-up", commented Dr. Nathan Zommer, CEO of IXYS Corporation.

Greater than 90% efficiency can be realized with the IX9908. An integrated high-voltage start up circuit with a digital soft-start provides quick turn on of LED lights. The IX9908 is available in an 8-lead SOIC package which allows for a compact LED driver PCB design.

The IX9908 features extensive protection circuitry against over-voltage, shorted winding, excessive die temperature, and logic supply under-voltage. That makes it a cost effective solution for a wide range of LED lighting applications, including dimmable and non-dimmable replacement bulbs, decorative lighting, LED tubes, and downlights. ■

# TI Introduces High-Power LED Driver for General-Purpose Area Lighting

Texas Instruments (TI) introduced a high-power, multi-topology DC/DC LED driver with adjustable switching frequency and current sense threshold that provides design flexibility and low electro-magnetic interference (EMI) for general-purpose area lighting, automotive headlamps and fog lights.


**The TPS92690, TI's latest LED driver, is a multi-topology DC/DC driver with adjustable switching frequency**

Key features and benefits of the TPS92690:

- Offered in AEC-Q100-qualified automotive or commercial grades.
- 4.5 V to 75 V input voltage range is suitable for boost, SEPIC, Cuk and flyback topologies in a wide variety of LED applications.
- Low-side adjustable current sense (50 mV to 500 mV) minimizes power loss and provides analog dimming control.
- Under-voltage lockout (UVLO), LED over-voltage, cycle-by-cycle current limit and thermal shutdown protect against faults and abnormal operating conditions.

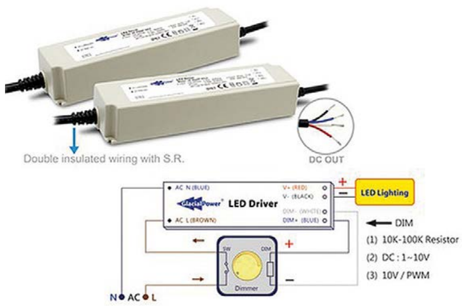
The TPS92690 is an N-channel MOSFET controller with low-side current sense designed to support step-up (boost) or step-up/step-down (SEPIC, Cuk, flyback) LED driver topologies.

The TPS92690 DC/DC LED controller includes a number of features that give designers significant flexibility to optimize their systems. For example, adjustable switching frequency (up to 2 MHz) and current sense threshold allow designers to optimize LED drive electronics for small size, high efficiency, or a balance of both. Separate pulse-width modulation (PWM) and analog inputs interface with common dimming control methods to adjust LED current or implement thermal fold back. An internal oscillator sets the switching frequency of the converter, but can be overdriven by an external clock for synchronizing switching frequencies with other converters in a design. Low-side current sensing enables design of low-EMI topologies, such as the Cuk converter, while still maintaining a single wire connection to the LED load.

The TPS92690 joins TI's diverse LED driver portfolio that includes the LM3466, LM3409 and LM3421/3/4 DC/DC LED drivers. ■

# GlacialPower Announces Two New 12-57 V LED Drivers

GlacialPower, a division of the Taiwanese technology manufacturer, GlacialTech Inc., is pleased to announce two new GlacialPower LED drivers for constant voltage (CV) and constant current (CC) LED lights – GP-RS45P and GP-RS60P – available in several options ranging from 12 V DC to 57 V DC. The drivers are also available with a 3 in 1 dimming (1-10 V / PWM / Resistor) function.




**GlacialPower's GP-RS45P and GP-RS60P LED drivers cover a large voltage range between 12 and 57 V with up to 48 and 60 W respectively**

Features:

- Class 2/II plastic driver housing design
- Double insulated wiring
- Universal AC input 90~305 VAC
- High power conversion efficiency: up to 89%
- Constant current and constant voltage
- Built-in active PFC
- 3 in 1 dimming function (optional)
- Protection: OVP / SCP / OTP
- IP67 approved
- Limited power supply (LPS) power unit

Both of the drivers are ideal for any indoor LED lighting solutions, as the IP67 approved plastic housing protects the drivers from possible dust or water damage such as rusting. Further, the double insulated wiring design ensures that if the wire is externally pulled, the strain relief bushing to the circuit board will not be exposed, preventing possible electricity leakages.

The GP-RS45P and GP-RS60P LED drivers offer a range of different options for indoor LED lighting needs. The output voltage of the two LED lights range from 12 VDC to 57 VDC. The GP-RS45P LED drivers deliver up to 48 W and the GP-RS60P LED drivers up to 60 W of power to the LED. For LED driver producers - safety standard certification UL8750 Class 2/II has been applied for and currently under review, however these drivers' specifications fully satisfy the criteria of UL1598 fixture safety standard. These specifications combined with cost-effective pricing and durable plastic housing makes these drivers excellent options for practically any constant voltage and constant current LED indoor lighting needs.

The drivers have a power conversion efficiency rate of up to 89%, which makes them highly energy efficient. Furthermore, true to the reputation of GlacialPower, the two new LED drivers are highly secure. In addition to the IP67 approved plastic housing the drivers have three different protections: Over Voltage Protection (OVP), Short-Circuit Protection (SCP) and Over-Temperature Protection (OTP).

GlacialPower's R&D team developed these LED drivers with the aim to eliminate the need for electronic transformers and to provide more energy-saving and environmentally-friendly LED products. ■

## Ultra-Compact 25 W LED Driver from RECOM

Due to the banishment of low efficiency illuminants, modern LED-lighting solutions are enjoying an increase in popularity and the lighting market is gradually adapting to these changes.

With the new RACD25 series, RECOM extends its broad product portfolio of high-quality LED drivers. Thanks to their long, sleek shape, the 25 W modules are ideally suitable as power source for the conversion from fluorescent lamps to modern LED technology.


**RECOM's new RACD25 is intended to be used in LED lighting systems that replace linear fluorescent lamps**

The drivers are optionally available with a constant output current of 500, 700, 1050 or 1400 mA and reach an efficiency of up to 85%. With their wide input voltage range of 90 to 295VAC they are perfectly qualified for applications worldwide. To meet the requirements of EN61000-3-2 Class C the modules are equipped with a standard active power correction, which also keeps the EMV load of the electricity grid low.

Since the RACD25 series is IP65 rated, it can be installed in moist facilities like garages or outdoor installations without any worries. The drivers are fully certified to EN61347 as well as UL8750 and come with a warranty of 5 years. ■

# TRP Adds Dimmable 20 Watt LED Driver

Thomas Research Products has introduced new dimming versions of their standard 20 W LED Drivers. Thomas Research Products is a leading manufacturer of SSL power solutions.


**Thomas Research Products now offers a dimming LED driver in the 20 W power range**

The new LED20W-D series drivers were created in response to customer demand. These products are constant-current drivers designed for use with standard 0-10 V dimmers. They feature a <10% to 100% dimming range and universal 100-277 V input. The dimming drivers will be available late in the third quarter of 2013.

TRP's new drivers provide all the same features as their popular standard LED20W series drivers. The Black Magic Thermal Advantage (TM) plastic enclosures are IP66 rated--making them suitable for outdoor applications. To keep luminaires performing, they offer over-voltage, over-current and short circuit protection. The drivers are UL Recognized for both US and Canada, and are CE certified. ■

# GWP Announces 75 Watt Constant Voltage LED Power Supply Availability

Green Watt Power, a division of Calex Mfg. Co., Inc., announces the availability of the GLV75 constant voltage LED power supply. The GLV-24-75 is a 24 Volt output 3.15A fully encapsulated IP67 rated power supply, ideal for LED lighting applications requiring that voltage and current rating. The GLV-24-75 is protected by over voltage protection, short circuit protection with auto recovery, over temperature protection and backed by Green Watt Power's five year warranty for years of reliable performance. The MTBF for the GLV75 is 200,000 hours.


**GWP's new constant voltage 75 W @24 V power supply**

The GLV-24-75 has a universal input range of 100 to 277 VAC. The power factor is 0.95. The efficiency of the unit is 86% typical with a full load input current of 1.2 A with a 110 VAC input. The noise and ripple is 360 mV peak to peak. Load regulation is 2%. The GLV-24-75 setup time is 3 seconds. Rise time is 200 ms. The voltage range tolerance including setpoint tolerance, line regulation and load regulation is +/-5%.

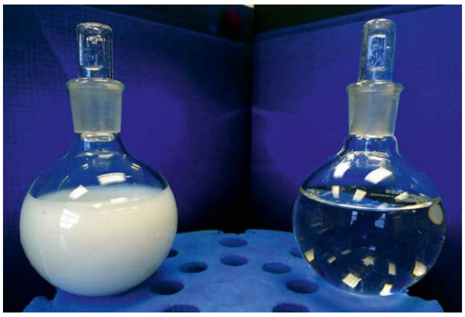
The operating temperature range is -35 to +70°C ambient. The storage temperature range of the GLV-24-75 is -40 to +85°C ambient. ■

# Pixelligent Technologies Expands PixClear™ Product Family

Pixelligent Technologies, the leading manufacturer of nanocrystal dispersions for demanding applications in the electronics and semiconductor markets, announces the addition of three new products to its PixClear™ Zirconia nanocrystal family – PixClear™-PG and PixClear™-PN formulations, and PixClear™ 4CAP. The two new formulations will provide device manufacturers with additional light management solutions for numerous display and lighting applications. The launch of PixClear™ 4CAP is a collection of our four most requested formulations that customers can use to accelerate the down-select process for their application requirements.

PixClear™ Advantages:

- High refractive index, 1.85+
- Highly transparent at visible wavelengths
- Low haze coating even at high nanocrystal loading, 80%+
- Improved scratch resistance and hardness
- Easily integrated into existing manufacturing processes



**PixClear™ (right) dispersed nanocrystals are highly transparent at visible wavelengths**

Pixelligent is working with leading global electronic device and materials companies to further improve the performance and efficiency of advanced electronic devices and protective films.

"The expansion of the PixClear™ product family has been in response to the overwhelming success of the initial PixClear™ product launch just over 90 days ago. The addition of these products further reinforces Pixelligent's commitment to deliver next generation products that enable our customers to deliver new functionality and introduce new applications to their end users. The significant growth of our customer base clearly demonstrates the commercial impact our technology is having in our target markets," commented Craig Bandes, President & CEO of Pixelligent.

PixClear™ and our custom dispersions are currently being used in touch screens, CMOS image sensors, HB LED and OLED applications, and clear protective films. When incorporated into modern touch screens and displays, the nanoadditives significantly increase light output and readability. PixClear™ also increases the light output and efficiency of lighting applications such as HB LEDs and OLEDs, and when incorporated into clear protective films significantly reduces glare/sparkle and improves scratch resistance.

PixClear™ is compatible with many of the most widely used varieties of monomers and polymers. Our proprietary dispersions enable Pixelligent to deliver highly transparent formulations with nanocrystal loadings in excess of 80% by weight, while reaching a refractive index as high as 1.85, both of which are levels that are unmatched in the industry. Additionally, PixClear™ provides great flexibility for index matching dissimilar materials and is compatible with modern high-speed polymer film forming techniques and most standard manufacturing processes. ■

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# TE Extends LED Holders Range

TE Connectivity (TE) announces the release of extensions for the Type Z50 LED holder. The TE Solderless LED Holder, Type Z50, is a circular LED holder family that is now extended to provide a solderless connection to the Philips Lumileds LUXEON® CoB LED array family (20x24), CITIZEN Electronics CLL030/032 and SAMSUNG LC026B/LC040B LEDs. These LED holders form the core of electrical, mechanical, thermal and optical interconnectivity. The Type Z50 LED holder effortlessly integrates with secondary reflector solutions from Carclo Optics and LEDIL enabling a shorter lead time and easier manufacturing process of LED fixtures.

**TE's Z50 type LED holders provide a quick and easy solderless connection**

The Type Z50 LED holders are available with either optics attachments or in a slim Low Profile form factor. As a participating member of the Zhaga Consortium, TE has designed the 50 mm diameter Type Z50 LED holder with optics attachment in such a way to enable customers to comply with the emerging standards and achieve Zhaga certified solutions. The Low Profile holder stands only 3 mm tall with a 45 mm diameter making it ideal for omnidirectional and customized optic applications.

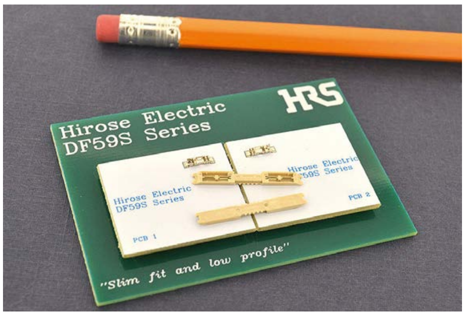
Additionally, the Type Z50 LED holder offers a unique mechanical construction which provides reliable down force and electrical connection over temperature extremes. Integrated poke-in electrical connections eliminate hand solder operations reducing costs associated with assembly and rework. Set on the same screw pitch and interchangeable with each other, the direct attachment of the Type Z50 LED holders to the heat sink uses standard screws securing the LED without damaging or cracking the substrates that could lead to latent field defects.

In order to make handling LEDs easier and faster when installing into fixtures, the Type Z50 holder provides a snap-in LED retention feature. Several optic attachment features are designed in close cooperation with Carclo Optics and LEDIL for optics to mechanically fit to the LED holder.

TE LED holder solutions are enabling the adoption of LED lighting by reducing applied costs and improving assembly of lighting OEM products. They are ideal for use in various indoor and outdoor lighting applications. ■

# Mono-Pole Connector from Hirose Optimized for LED Lighting

Hirose Electric, a leader in the development of innovative connector solutions, has developed the DF59S Series, a mono-pole connector that is optimized for LED lighting applications. The board-to-board connectors feature a housing free receptacle that produces a slim fit and low profile when mated, making this an excellent connector for high density LED applications.
The DF59S Series has a unique "stress-free contact" that provides a ± 0.5 mm floating function in the X and Y directions and ± 0.2 mm in the Z direction.




**Hirose Electric's new board-to-board connectors is designed for high density mounting in LED modules**

"The DF59S Series connectors are ideal for high density, low power LED applications with limited space between LEDs," said Rick van Weezel, vice president of sales and marketing for Hirose Electric USA. "This connector series provides a solution for LED engineers hoping to maximize board space while ensuring the optimal performance needed for an application to excel."

Depending on the distance between the two connector sets, the DF59S Series connectors have a rated voltage range of 200 V to 350 V, and a high-current capacity of 3 A. The DF59S series is RoHS and REACH compliant, and is classified as a halogen-free product.

Pending UL application, the DF59S Series connector's creepage distance from the PCB edge to the contact pad satisfies the 250 V condition requirement of IEC60664-1. ■

# Cree Extends LED Bulbs Series to Meet Growing Consumer Demand

Just four months after introducing "The Biggest Thing Since the Light Bulb™", Cree announces the ground-breaking Cree® LED BR30 Flood Light. The Flood Light leverages the same technical breakthroughs that made the Cree LED bulb possible – delivering consumers a flood light that looks and lights like a traditional incandescent BR30 but uses 85% less energy and is designed to last 25 times longer than comparable incandescent flood lights.


**Cree LED BR30 Flood Lights are available online at The Home Depot**

Featuring the same shape, same glass dome and same color light of the typical incandescent flood it replaces, the new Cree LED Flood Light blends seamlessly with existing BR flood lights and gives consumers the flexibility to upgrade one or multiple bulbs without any noticeable difference – especially in recessed lighting applications. In fact, the only difference they're likely to notice is lower utility bills. The new LED Flood Lights are backed by Cree's industry-leading 10-year limited warranty and available exclusively at The Home Depot®.

"We're in the midst of a consumer lighting revolution and Cree is truly enabling people to change the way they light their home forever," said Chuck Swoboda, Cree chairman and CEO. "Cree is committed to solving consumer problems by delivering products that are better than those being replaced, while maintaining the experience people expect. The new Cree BR30 is another milestone innovation to drive 100 percent adoption of LED lighting, saving consumers money and reducing overall energy consumption."

Featuring game-changing design, beautiful warm light, long-life and an affordable price-point, the BR30 Flood Light is ideal for use in most common track, recessed and hard-to-reach fixtures. The Cree LED BR30 Flood Light was conceived to make quality LED lighting affordable with a retail price of $19.97 for the soft white (2700 K) 65-watt incandescent replacement. For those who prefer a cooler light color, the Cree LED BR30 Flood Light is also available in a daylight (5000 K) color with a retail price of $21.97. The economical bulbs pay for themselves and then pay customers back for years to come. The new LED bulbs turn on instantly and are dimmable with most standard incandescent dimmers. Both versions of the new Cree bulbs deliver 650 lumens and consume only 9.5 watts.

## Green Creative Announces Highly Efficient High CRI 7W MR16 LED Lamp

Green Creative LLC, the Commercial grade LED lighting manufacturer announces the availability of its new Crisp LED Series MR16 7 W High CRI directional lamp. This 45 W halogen replacement has a typical CRI 95 and features the latest in LED color rendering technology. Utilizing a unique LED package and bin selection to achieve excellent R1-R14 values. Therefore this compact lamp creates true and vibrant colors across the whole spectrum.

**Green Creative's new MR16 7W High CRI lamp has exceptional R9 & R14**

LED CRI testing analyzes the chromatic effect of a light source over a scale of 14 standard colors (R1-R14) and assigns each tested color a value (100 is perfect). CRI is then calculated by taking the average of the R1-R8 values. This same CRI commonly seen on packaging and specification sheets can mislead end users because it only refers to eight of the tested colors.

Although the R9-R14 colors are measured, they have no impact on a lamp's CRI rating. So while some LEDs claim to have a high CRI, they may do a poor job rendering other key colors. Green Creative's new MR16 7 W High CRI lamp has exceptional R9-R14 values including typical R9 95 and R13 95 ratings. This ensures reds (R9) look richer and skin tones (R13) look natural.

Unlike most high CRI LEDs, the Crisp Series MR16 delivers outstanding color rendering without sacrificing efficiency. At 465 lm, this 1:1 halogen form factor lamp features an extremely high 66 LPW efficacy and is 50% more efficient than any other high CRI 45-50 W replacement MR16.

Green Creative designed this lamp specifically for applications that demand accurate color rendering such as retail, food, museums, and art galleries. In the past, these applications had to choose between having either high color rendering or energy saving efficiency. Now they can have both.

The new MR16 7W High CRI comes in 3000 K and 2700 K CCT as well as narrow flood and flood beam angles, is dimmable, UL listed Class I & II, and backed by a 3 year warranty. Energy Star qualification is currently pending.

## Cree Announces $99 LED Street Light for Residential Streets

Cree, Inc. announces an industry-changing technology breakthrough for the LED street lighting market. The XSPR™ LED Residential Street Light delivers better lighting while consuming over 65 percent less energy at an initial cost as low as $99 for common applications.

The new Cree® XSPR streetlight is the ideal replacement for municipalities and cities using outdated high-pressure sodium fixtures up to 100 watts and can deliver payback in less than one year.*

* Payback is calculated against high-pressure sodium and based on municipal usage of 12 hours per-day and the national average of $0.11 per kWh electric costs.

**Cree's new XSPR streetlight uses 65 percent less energy while delivering better light quality and rapid payback due to the low initial cost**

"With the low initial price of the XSPR streetlight and the dramatic energy savings, wholesale replacement of existing street lights becomes a simple choice," said Al Ruud, Cree vice-chairman, lighting. "Utilities and city managers can now improve the lighting in their neighborhoods, save energy and see payback in less than a year. Why would anyone choose otherwise?"

Extending the technical breakthroughs of the XSP Series LED Street Light portfolio, the 25-watt and 42-watt XSPR street light is designed to replace up to 100-watt high-pressure sodium streetlights, reducing energy consumption while improving lighting performance. Cree's NanoOptic® Precision Delivery Grid™ optic technology achieves better optical control than traditional street lighting fixtures and efficiently delivers white uniform light for safer-feeling communities. In addition to a low initial cost and significant energy savings, the XSPR streetlight is backed by Cree's 10-year industry-leading warranty.

## Dialight Reveals 107 LPW LED High Bay with Integrated Long Life Power Supply

Dialight, the innovative global leader in LED lighting technology, announced its innovation program has gained UL certification and CE compliance for its DuroSite® LED High Bay and Low Bay product portfolios for industrial applications with a new long life power supply.
With efficiencies up to 107 lumens per Watt, the versions with the new power supply will be available in 17,000 - 3,800 lumen output fixture versions.

**Dialight's new LED high bay sets the standard with a high efficiency of 107 lm/W and industry leading 10 year full performance warranty**

"This latest achievement in our LED power supply development gives our customers up to a 7% increase in efficiency across the high bay and low bay portfolio," said Roy Burton, Dialight's Group Chief Executive. "Backed by our comprehensive 10 year full performance warranty, our industrial lighting fixtures continue to be some of the most widely installed LED fixtures available today." Dialight's in-house power supply development is already proven to deliver extremely reliable and effective LED fixtures with significant benefits - superior lumen per Watt efficiency, high power factor, low THD, various input supply options and high transient surge protection. With full quality control over every component within the electronic system, Dialight's designs are based on topologies and techniques developed over several years.

Maintenance of conventional HID lighting fixtures in these rugged environments can be very costly - bulb changes require permitting, scaffolding to be erected, processes to be shut down and multiple personnel for safety and supervision. This can truly be seen in areas prone to extreme temperatures and shock or vibration. With conventional HID lighting proving to be unreliable in these conditions, the highly efficient Dialight high bay offers a rugged and durable fixture while providing a total cost of ownership savings.

This newly integrated solid state power supply is the latest innovation in Dialight's rapid technology development program that has turned out a number of first-to-market technologies, including the first Class I, Div. 2 hazardous location certified high output LED fixture available with a 10 year full performance warranty.

# Rensselaer Researchers Identify Cause of LED "Efficiency Droop"

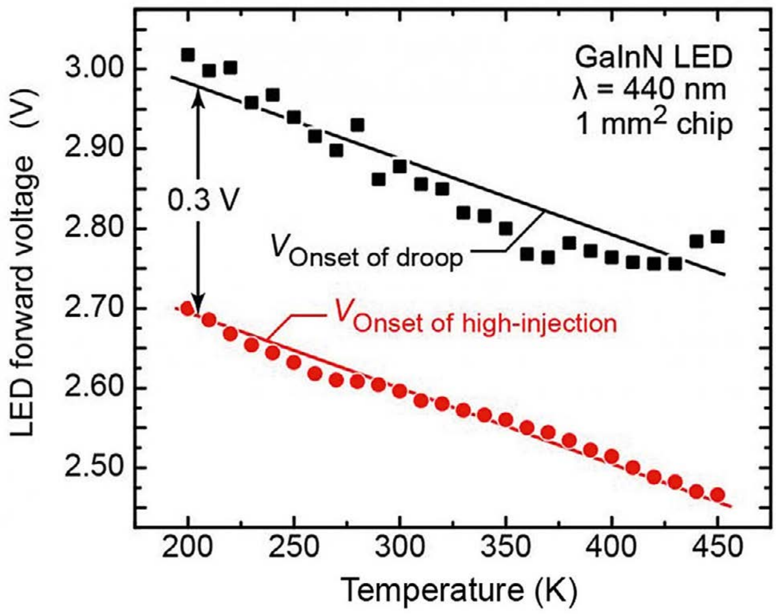
Rensselaer Polytechnic Institute researchers have identified the mechanism behind a plague of LED light bulbs: a flaw called "efficiency droop" that causes LEDs to lose up to 20 percent of their efficiency as they are subjected to greater electrical currents. Efficiency droop, first reported in 1999, has been a key obstacle in the development of LED lighting for situations, like household lighting, that call for economical sources of versatile and bright light.

In a paper recently published in Applied Physics Letters, the researchers identify a phenomena known as "electron leakage" as the culprit. The research offers the first comprehensive model for the mechanism behind efficiency droop, and may lead to new technologies to solve the problem, said E. Fred Schubert, the Wellfleet Senior Constellation Professor of Future Chips at Rensselaer, founding director of the university's National Science Foundation-funded Smart Lighting Engineering Research Center, and senior author on the study.

"In the past, researchers and LED manufacturers have made progress in reducing efficiency droop, but some of the progress was made without understanding what causes the droop," said Schubert. "I think now we have a better understanding of what causes the droop and this opens up specific strategies to address it."

Light-emitting diodes take advantage of the fact that high-energy electrons emit photons, i.e. particles of light, as they move from a higher to a lower energy level. The light-emitting diode is constructed of three sections: an "n-type" section of crystal that is loaded with negatively charged electrons; a p-type section of crystal that contains many positively charged "holes;" and a section in between the two called the "quantum well" or "active region."

David Meyaard, first author on the study and a doctoral student in electrical engineering, explains that electrons are injected into the active region from the n-type material as holes are injected into the active region from the p-type material. The electrons and holes move in opposite directions and, if they meet in the active region, they recombine, at which point the electron moves to a lower state of energy and emits a photon of light. Unfortunately, researchers have noticed that as more current is applied, LEDs lose efficiency, producing proportionally less light as the current is increased.




**Voltage at the onset of high injection and voltage at the onset of the efficiency droop (i.e., the peak-efficiency point) as a function of temperature**

Meyaard said the team's research shows that, under the "high current regime," an electric field develops within the p-type region of the diode, allowing electrons to escape the active region where they would otherwise recombine with holes and emit photons of light. This phenomenon, known as "electron leakage," was first proposed more than five years ago, but Meyaard said the team's research is the first incontrovertible evidence that it is the cause behind efficiency droop. Meyaard said the team identified the electric field as it began to build up, and showed that, after a sufficiently strong field is built up, the electrons escape out of the active region.

"We measure excellent correlation between the onset of field-buildup and the onset of droop," said Meyaard. "This is clear evidence that the mechanism is electron leakage, and we can describe it quantitatively. For example, in one key result reported in the paper, we show the onset of high injection and the onset of droop and you can see that they are very nicely correlated. And that was just not possible in the past because there was really no theoretical model that described how electron leakage really works." Schubert said their work shows that because electrons have a greater "mobility" than holes, the diode is made from disparate types of carriers.

"If the holes and the electrons had similar properties, there is a symmetry; both would meet in the middle, where the quantum well is, and there they recombine," said Schubert. "What we have instead is a material system where the electrons are much more mobile than the holes. And because they are very mobile, they diffuse more easily, they also react more easily to an electric field. Because of that asymmetry, or disparity, we have a propensity of the electrons to 'shoot over' and to be extracted from the quantum well. And so they don't meet the hole in the active region and so they don't emit light."

Meyaard and Schubert said the team has now turned their attention to developing a new structure for LEDs, based on the model, which they look forward to introducing.

The paper, published in the June 27 edition of Applied Physics Letters, is titled "Identifying the cause of the efficiency droop in GaInN light-emitting diodes by correlating the onset of high injection with the onset of the efficiency droop." ■

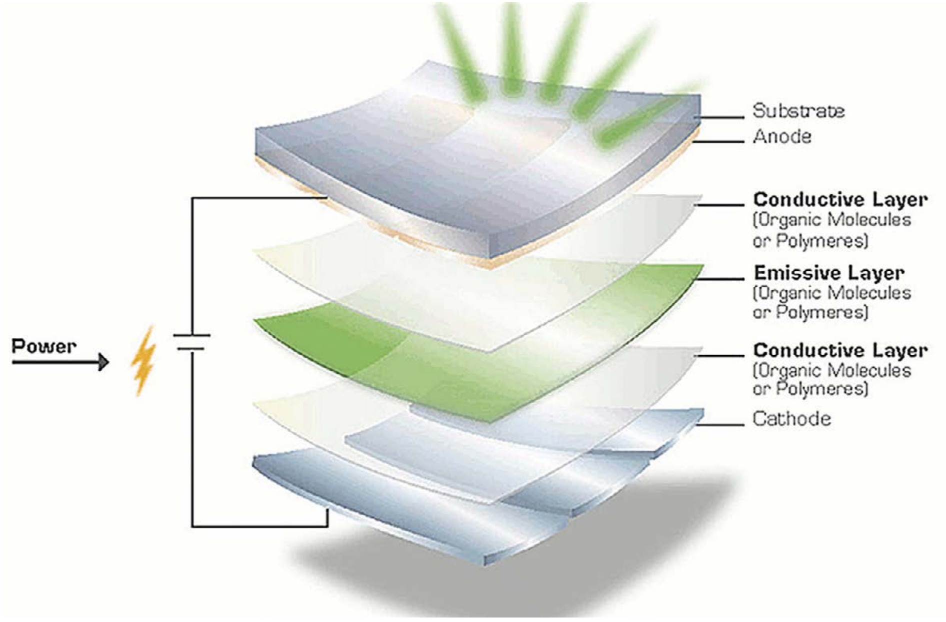
 

# Supported Project "cyCESH" for Cost-Efficient Printed OLEDs

On June 1, 2013, BMBF launched the project cyCESH involving cynora GmbH, Novaled AG and the University of Regensburg with the workgroup of Prof. Dr. Hartmut Yersin.

The project is set to run for the duration of three years with a total funding of 6.1 million Euros. The research of new soluble materials for the inexpensive production of OLEDs and the production of OLED devices with high efficiency are the main focus of the project.

The new printable materials make it possible to manufacture OLEDs with simpler and cheaper printing processes. Currently conventional OLEDs are still mainly being produced by expensive vacuum processes. "Through our collaboration with Novaled and Prof. Yersin of the University of Regensburg, we combine, within a team of experts, a comprehensive and specific know-how and can take it to the next step in OLED development," said Dr. Thomas Baumann, Managing Director of cynora.




**Schematic structure of an OLED (Credits: cynora)**

"Our consortium strives for the overall goal of developing mass-market materials and methods for production of OLEDs."

The collaboration of these project partners guarantees an optimum coverage of the value chain. Combined, the areas of material development (Prof. Yersin), the subsequent synthesis and optimization of the materials (cynora), as well as the application of solution-based-processed, doped transport layers (Novaled) form a complete comprehensive partnership for OLED applications.

## CORRECTION

In the print version of LpR 38 an unfortunate mistake was made when assigning company names to two of the authors. The correct article title, author and company should read as follows:

**Key to Next Generation Advancements in Lighting** - by Gregory Cooper, Pixelligent Technologies LLC
**Handheld Photometry Supports LED Lighting Design** - by Norbert Harkam, SalesLink GmbH / UPRtek

LED professional, and in particular the Editor-in-Chief, Arno Grabher-Meyer, apologize for any inconveniences caused.

## WEBINARS


### Obtaining the Highest Candle Beam Power for Spotlights

Lumen density in the LED source is very significant in final design. Obtaining Center Beam Candle Power is a goal in high quality applications including retail and architectural lighting. High Power LEDs are the perfect solution to creating high lumen intensity from a very small light emitting source. Creating a very high lumen per mm square enables the highest center beam candle power in a system. Where other COB's need ~35-35mm for high lumen packages, LUXEON S5000 can achieve 8000 lumens in a Light Emitting Surface of just 17mm. Creating great spotlights has never been easier.

To view the webinar, register at **www.led-professional.com/Webinars**

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# LpS 2013 – The Hub for Developments and Innovation in LED & OLED Technologies

Discussions, acquiring information, generating ideas, making new contacts and finding the right business partners is the idea behind the LED professional Symposium +Expo, which has established itself as the leading LED technology event in Europe. Expectations of the over 1,000 visitors anticipated this year are bound to be surpassed with almost double the amount of lectures and workshops compared to 2012.

Know-how is the basis for developments and the key to success. With a total of 46 lectures presented by international experts, the LpS offers a broad range of subjects this year. The presentations cover the subjects of Solid-State-Lighting from LED and OLED light sources to solutions in the area of implementation. Pars Mukish, Market and Technology Analyst at Yole Développement, will be taking up the issue of "OLED for Lighting" on the first day of the event. Contrary to OLEDs in the area of displays, their role in the lighting industry is still in its infancy. They have potential for the future but will have to compete with established LED technologies in the area of Solid-State-Lighting (SSL). Mr. Mukish sees the biggest challenge as identifying the spark market that allows technology to develop a production scale momentum and create a marketing window that demonstrates the advantages and possibilities of the technology to consumers.

Dr. Matteo Meneghini from the University of Padova will give insights into one of his areas of research, namely: "Degeneration Mechanisms of High Power LEDs". In the course of an extensive study he examined the most important degradation mechanisms. He and his research team carried out stress tests over thousands of hours in order to see the effects of the operating current and storage temperature on electro-optical properties. The results can be used to improve the design of advanced light sources for SSL.

Four sessions are dedicated to drivers and controls that is one of the core themes this year. Stefan Zudrell-Koch, the director of strategic marketing and business development at Dialog Semiconductor will be giving a talk on this subject titled "Digital Processing Techniques in Retrofit Lamp Driver ICs". Today, off-line AC/DC LED drivers are dominantly operated and controlled by mixed signal control ICs; the first generation of digital power management ICs. IC technologies with a substantially higher scale of integration are available at low cost today. They allow for large-scale integration and substantially more complex logic structures to be implemented compared to today's solutions. Digital systems offer free configurability. These new systems are enabled with unprecedented performance, flexibility and ease of use. Mr. Zudrell-Koch will demonstrate how such technologies help master challenges in retrofit lamp design, drive cost reduction, and make LED lamps future proof.

Six workshops are being offered in two parallel tracks. The workshops offer detailed analyses in the areas of Reliability and Thermal Testing, Standardization, 3-Dimensional System Designs and Optics, Printoptical Technology, Computer Based Design of LED and OLED Systems as well as Qualification and Reliability. On Day 1, Mentor Graphics is offering a workshop titled "Reliability & Thermal Testing". The workshop explains how the junction temperature depends on both the LED package and the system on which it is mounted. Attendees learn how thermal performance of LED packages and systems can be measured and characterized for reliability improvements.

On Day 2, Underwriter Laboratories (UL) will hold a workshop on the topic of standardization. Here, the development of standards, IEC updates, energy efficiency programs (ES, LF, DLC, ErP), Zhaga updates, lighting controls and RoHS updates will be shown.

Day 2 is also host to the LPKF and Essemtec workshop on 3-Dimensional System Designs and Optics. Participants will get a complete overview of an innovative production process for creating three-dimensional LED layouts for a wide variety of lighting sources (SSL, automotive lighting, etc.). Each LDS process step from the selection of thermally conductive materials, functional LDS coating of the heat sink, laser structuring, dispensing of glue or solder paste for fixing the LED on the substrate to the final 3D placement of the LEDs on components will be discussed.

Following that, there will be a workshop entitled "Printoptical Technology" presented by LUXeXcel. Printoptical technology makes it possible to produce 3-dimensional optics with which lenses and light distribution structures are made. The changes in the lighting industry that this new production technology brings will be discussed.

The last day of the symposium will also host the "Design Workshop" from Arrow, NXP and Transim. Deep-seated knowledge in the areas of component data and system elements such as cooling devices, optics and electronics that is needed for the design of LED lighting systems in order to be able to attain the necessary light requirements will be discussed. Participants will get an overview of modern simulation and configuration tools that are designed to improve R&D performance, quality and costs processes.

Cree will also be running their workshop on the subject of "Testing" on Day 3. This will be a discussion of step-by-step improvements of an existing luminaire design. Participants will learn how to differentiate and make use of several experimental runs based on CREE TEMPO test results to optimize their luminaire design process.

This year the Tech Panels will be open to the public. Dietmar Zembrot (President of LightingEurope and CEO of TRILUX), Klaus Vamberszky (Executive Vice President of Technology at Zumtobel), Christian May (Head of Business Unit Lighting and Flexible Integration at Fraunhofer), Matteo Menehgini (Ph.D. Professor at the University of Padova) and Henk Veldhuis (Chair of the Technical Advisory Working Group of the Connected Lighting Alliance) will be discussing "LED & OLED Lighting Innovations- How to Break Through" on September 24$^{th}$. To round off the LpS 2013 there will be a discussion by the international press on the subject of "Lessons Learned". In order to make the Tech-Panels even more inter-active, they will be put online in the form of a live webinar. This will make it possible for those not able to attend personally to take part in the discussions.

On the first evening, Zumtobel will be presenting an innovative light installation at the Vorarlberg Museum. At the same time, Peter Kogler, a well-know artist, will be using the museum's façade for his light show.

On the second evening there will be live entertainment and dinner on board the MS Vorarlberg. Like at the LpS 2012, participants can relax and network while cruising the lake. ■

 

# Solid-State Lighting Considerations

Siegfried Luger, Founder and CEO of Luger Research - Institute for Innovation & Technology, summarizes some important results in the lighting area out of research studies and explains the importance of and method for technology forecasts. Trends of Engineering System Evolutions (TESE) are suitable for predicting future product generations and for extracting the winning technology approaches for lighting strategies.

The demand for energy efficiency across all sectors of our society is growing. Overall, lighting accounts for approximately 19% of the worldwide electricity consumption which can be reduced with the use of LED and OLED light sources. It isn't only the general lighting market that is being fundamentally changed by Solid State Lighting technologies; it's the whole lighting industry. Predictions for the next five to seven years are that we'll see more LED/OLED performance increases along with continuous price declines. For example, state-of-the-art white LEDs have already reached 30-50% efficiency, have luminous efficacies of 100-150 lm/W and a color rendering index (CRI) of 80. Target values for warm white LEDs in the next 10 years are: 50-60% efficiency, more than 200 lm/W efficacy and a CRI of over 90. State-of-the-art OLED products are around 50 lm/W today. While their efficacy is expected to always stay below that of LEDs, the added value of OLED technology will come from its size, flexibility and opportunities for new applications. But a lack of information and awareness about the availability and performance of energy efficient lighting can hinder the implementation of energy efficient lighting programs around the world.

The EU green paper stated that in 2010, total market revenues of general lighting worldwide were around 52 billion Euros of which close to 30% was spent in Europe. By 2020, the world market is projected to reach 88 billion Euros with Europe's share decreasing to less than 25%. Current market penetration of SSL in Europe is very low: the LED market share (in value) reached 6.2% in 2010. Several studies predict that SSL will account for more than 70% of Europe's general lighting market by 2020. Europe's lighting industry has a clear role to play in the transition to SSL. It is large and world-class, and is ready to build upon its strengths in conventional lighting in order to capitalise on this emerging technology. However, European SSL market uptake is slow and SSL related research, innovation and cooperation activities are fragmented. In contrast, in other regions of the world, especially Asia and the USA, the lighting industry is moving ahead quickly, with the help of significant government support. Regulations to support more efficient forms of lighting has increased and became a global theme with the rapid move to LEDs. In post Fukushima Japan we have the most impressive example with 50% of down lights sold in 2012 being LED based. Japan and China are leading the transition to LED lighting.

First studies on the full life-cycle impacts of LED lighting compared to other lighting technologies have already been carried out. The full life-cycle impacts need to be further monitored as LED technology evolves. In the future, SSL applications may be widely deployed beyond the mere replacement of existing lighting systems. In the long run, this could reduce the expected energy savings, known as the rebound effect. Experts from Sandia National Laboratories published a study in the "Journal of Physics D: Applied Physics" that energy consumption will increase even with the use of energy efficient LED and OLED technology due to the fact that the better the artificial lighting is, the more it's used in general. Mr. Tsao, head of the research project, stated, that the annual costs for lighting stayed constant at 0.72 percent of the GDP over years. Artificial lighting and prosperity are closely connected and more light would make sense because today's brightness levels for indoor applications just reach about 1/10 of that of a cloudy day. Not to forget the demands for lighting in developing and emerging countries. Researchers expect that light consumption will increase by the factor of 10 within the next 20 years, doubling energy consumption. Their simulation model included the global economic output, the energy prices and the efficiencies of lamps. The study showed that the overall required energy for lighting will only decline if the electricity prices are tripled. However, LED technology may help to overcome the loss in human productivity based on more and better lighting.

 

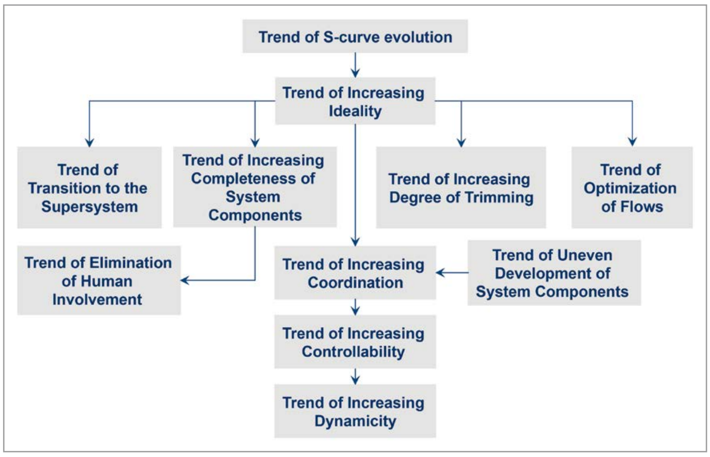


**Figure 1:** **Mr. Genrich Altshuller's "Trends of Engineering System Evolutions" (TESE) are also applicable to LED & OLED lighting technologies**

Another research study, founded by the Austrian government investigated the energy efficiency of shop lighting. The researchers from e7, items Innovation and Technology Management and Luger Research found out that a 1:1 replacement of conventional lamps with LED lamps is far too little. The great potentials of LED lighting systems (up to 50%) can only be achieved when the lighting systems are adapted to the needs of the respective applications and in combination with the use of intelligent control modes with dimmable lighting systems. Two shop applications from a petrol company and a textile chain store were investigated under real planning conditions.

Nevertheless, the challenges of phasing out old, traditional lighting technologies and ramping up new technologies are huge.
The upstream market (LED light sources, etc.) has been characterized by overcapacity and falling operating margins in 2011/2012 with a cyclical recovery in 2013 underway.
Many upstream players, both traditional and newcomers, made moves into downstream (luminaries, etc.) with an aim to escape the eventual commoditization and standardization of a large part of the upstream market. Philips started this move and built the most comprehensive downstream offering in the industry. However, it is still unclear to what degree a downstream expansion strategy will be successful or needed for upstream players.
The LED industry is rather fragmented. It is usually divided into five segments: materials, equipment, finished lamps and components, luminaires and systems, and finally lighting services and solutions. In the medium and long run, the latter is expected to become important as consumers could be provided with lighting services instead of lamps and fixtures.

We also see another new important situation on the lighting market. The "merging" lighting with the fast and innovative semiconductor industry requires new processes, structures, partners, alliances and a new understanding of the lighting sector itself. Restructuring the lighting business to enable potentials for new, environmentally friendly lighting is required to make a substantial contribution to the world's energy situation. Deployment of smart lighting is of interest to building owners, governments, utilities, and many other stakeholders as it can help to further reduce energy consumption. Controls can allow perceived light quality to match lighting codes precisely and allow LEDs to be powered at lower current levels, extending their lifespan, as dimming an LED makes it run cooler, which in turn makes it more efficient and reduces depreciation.

New and enhanced technologies are still the major innovation drivers in semiconductor lighting. Technologies are being increasingly merged on a sub-system level while diverse industries are intensifying their collaborations. But the key question remains: "What will the winning approaches be in the years to come"?

The "Trends of Engineering System Evolutions" (TESE), which are derived from the studies of Mr. Genrich Altshuller, the founder of TRIZ, are common valid trends for engineering systems and therefore also applicable to LED & OLED lighting technologies (Figure 1). Engineering Systems are evolving by adding useful functions, reducing or eliminating harmful functions and by reducing costs. This increased idealism is obtained through the "Transition to the Supersystem" (e.g. Multi-chip arrays, remote phosphors, central control and supply units, etc., "Increasing Degree of Trimming" (e.g. Driverless systems, single-stage converters, zero-binning, etc.), "Optimization of Flows" (e.g. Heat-spreader, analogue dimming techniques, etc.), "Increasing the Degree of Completeness (e.g. Digitalization of control units, etc.), "Elimination of Human Involvement" (e.g. Self-adjusting systems, self-calibrating systems, etc.), "Increasing Coordination" (e.g. Form factors, white colored PCBs, nano- and microstructured chip surfaces, etc.), "Increasing Controllability" (e.g. externally controlled / updatable systems, self-systems, etc.), "Increasing Dynamization" (e.g. OLEDs or LEDs with flexible substrates, resonant mode control, wireless control, etc.). There are still fundamental developments on all system levels and in every single trend recognizable, knowing that LED lighting systems are still in an early development phase, stage 2 of the life-time S-curve.

The TESEs, representing the technology trends, derived intellectual properties, R&D networks and market/ business potentials altogether create the building blocks for new lighting strategies. Years ago, Siemens started the "Picture of the Future" approach to forecast new product generations. The basic idea is to combine and align future market opportunities with technology trends for the future, creating a new picture of the world. One part of this approach is the extrapolation of technology trends known as TESEs. The better we can forecast the technology developments, the better we can imagine new and future products.

**The EU report "Accelerating Deployment SSL Report" highlights the following, ongoing R&D efforts:**

- Developing LEDs and OLEDs with higher efficacy, and higher lumen output at different colour temperatures.
- Development of cost-effective lamps which can replace incandescent and CFL lamps. There are some LED lamps replacing the 60 W incandescent bulbs available from €10 - €20, but products delivering the same quantity of light, such as the Philips Ambient LED, are available on the European market at around €40-€60.
- Better cooling with passive methods and improved low-cost heat sinks. Novel methods include an ionizer, where a mesh of wires near the LED chip creates an electric field with a small electric charge. The ions create a breeze, which in turn eliminates heat. Another approach uses a tiny device that creates a vortex of wind near the chip to dissipate heat.
- Quantum Dot LEDs: In recent experiments, LEDs emitting blue light were coated with quantum dots. These dots glow in response to the blue light of the LED, resulting in a warm yellow light similar to that of incandescent lamps. Quantum dots have unique properties which enable them to create almost any color on the visible spectrum. This increases the possibilities of LED use in display screens, as well as lighting.
- Development of high efficiency and long-life LED drivers.
- Development of integrated controls, which can have embedded sensors for intelligent control.
- Development of lamps without DC converters for better efficiency, as well as to decrease costs and weight.

One event which focusses precisely on LED and OLED lighting technologies is the annual, international LED professional Symposium +Expo in Bregenz, Austria (see www.LpS2013.com), which takes place in the Festspielhaus Bregenz on September 24th to 26th. A distinguished advisory board selects the "Winning Technologies" from the technology field every year and the highlights are presented in Bregenz. Based on lectures, workshops, tech-panels and an exhibition, visitors are able to understand the key influence factors for strategic decisions which have to be made for the coming year.

The dynamism in the field of LED and OLED lighting is huge and it's not an easy task to get a clear picture even of the near future due the complexity on all system levels. The bottom-up approach in forecasting the future developments is a valid process and it delivers fact-based results for business strategies. LED and OLED lighting is and will be the winning technology in the end, but precise predictions of available technologies are an important factor for giving the right answers - strategies for lighting. ■

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# Status of Micro- and Nanostructured 3D LED Technologies

Conventional LEDs are planar, two-dimensional (2D) devices that emit light from a thin material layer at or near their flat surface. The vast majority of LEDs are made of GaN and InGaN material requiring expensive substrate wafers made of sapphire, silicon carbide or gallium nitride. The 3D WireLED technology uses silicon wafers for wafer diameters of 8 inches or larger. On each wafer, millions of vertical microwires and microrods of GaN are grown, each with a diameter of less than one micron. Mr. Arno Grabher-Meyer and Mr. Siegfried Luger from LED professional, talked with the General Manager of Aledia, Mr. Giorgio Anania about the status of this innovative technology.

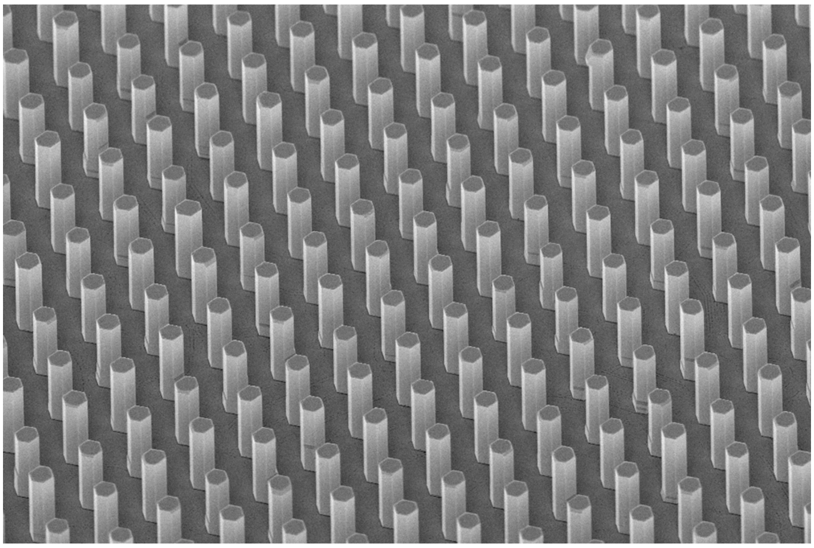

**Figure 1:** **Nanowires are the basis of the 3D LED technology that promises several advantages over the conventional LED technology**

**LED professional:** Before we go into details, can you tell us what the principle structure and performance of your 3D technology is?

**Giorgio Anania:** We are still developing these products so there are still unknowns related to performance. We are working with Gallium-Nitride with an m-plane instead of c-plane growth so we are in a different plane structure. However, the rest uses Gallium-Nitride. The fact that we have the quantum-wells wrapped in cylinders around the micro-wires, so co-cylindrical, makes the differences in the way the light is emitted - but the physics is the same as for m-plane, flat Gallium-Nitride.

**LED professional:** Let's go back to the basic idea for the technology. What were the problems you were trying to overcome with the 3D technology?

**Giorgio Anania:** The basic argument is as follows: The industry has basically dropped the price of lumens per dollar by increasing the lumens or, let's say, the efficiency. That starts getting flatter as the time moves on. Today, the approach used by the optics world is not made for high-volume, so it's expensive. In order to address the cost issue, there's no point in starting up with a 5% better solution than some of the Asian giants. We must think of an approach that is completely different; an approach with different characteristics. With microwires we can completely disconnect the light-emission, which can be a perfect micro wire crystal, from the substrate, just to be used as a carrier. The point is, you can disconnect the microwires from the substrates so you get a cheap substrate and and also have a large amount of substrate for mass production. In the 2-D world you will not get big cost savings by using GaN on Silicon instead of GaN on sapphire. The main advantage is that you can use the silicon CMOS foundaries. But you don't get big cost savings because you still have over stresses related to putting the GaN coating on. If you put a big GaN buffer layer on silicon, which has to be thicker than on sapphire, it requires longer process times in the reactors. But the stress in the material still remains and this is exactly the point where the 3D concept shows the big advantages; especially when we build up the microwires on silicon instead of a separate GaN buffer layer.

 


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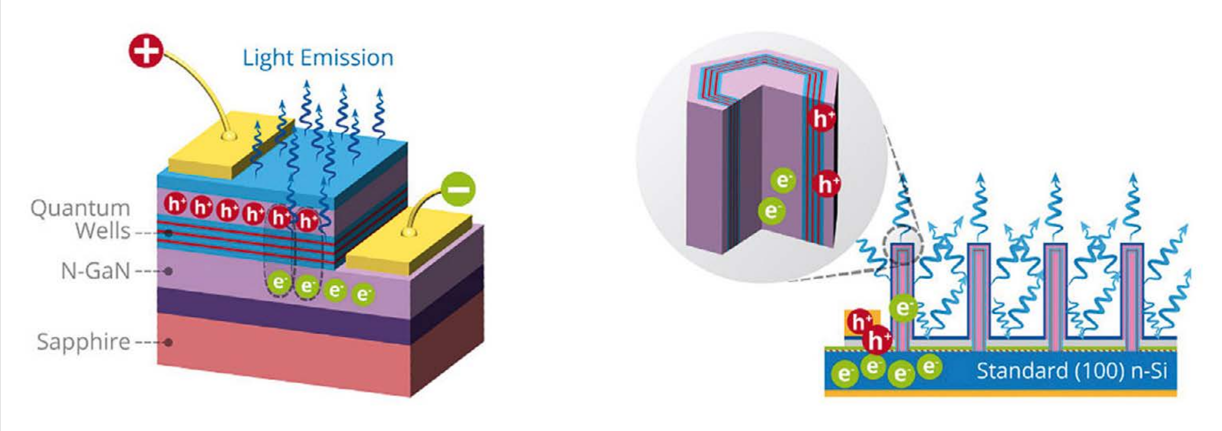


**Figure 2:** **Comparison of the conventional 2D (planar) LED technology (left) and the 3D microwire technology (right).**

**2D LEDs:**
- **Small, expensive substrate**
- **Slow MOCVD growth process (high capital expenditure)**
- **High materials consumption**
- **LED-specific manufacturing plants**
- **Light emission area = at most the 2D area**
- **Single color on one wafer**

**3D LEDs:**
- **Large, economical substrate**
- **Fast MOCVD growth process (low capital expenditure)**
- **Low materials consumption**
- **Existing high-volume silicon wafer fabs**
- **Light emission area = up to 3x the 2D area = more light/mm² or less current density, less efficiency droop**
- **Multiple colors on one wafer or even on one chip**

**LED professional:** How large can the wafer sizes be with your technology and what other factors are related to the cost side?

**Giorgio Anania:** We can start at 8 inches because it's cheap. Since most of the fabs in microelectronics moved from 8 to 12 inches, the remaining 8 inch fabs are offering lower prices. As soon as 12 inch wafer production gets cheaper we will move to 12 inches as well. The 3D LED technology with microwires and without any GaN buffer is completely scaleable in terms of wafer sizes. The breakthrough of this technology is really that the emitting crystal is stress free even when processing big wafer sizes. Our 3D technology is not just a silicon based LED because microwires have a much lower material content than the GaN buffer layer, it's the throughput which is very fast through the MOCVD machine and the fact that you can use generally available plants and that you can have more surface area.

**LED professional:** There are a lot of arguments for 3D micro wire technology, costwise. What about the performance figures?

**Giorgio Anania:** There are some non-cost advantages you can get which are quite significant.
For example, a 1 mm² 2D LED chip will have approximately 1 mm² of emitting area. Theoretically, with the micro wire technology you have the potential to increase surface area - in other words you'll get more light out of an 3D 1 mm² LED chip compared to the 2D technology.

**LED professional:** Are there limits in the lengths of the microwires? How far forward can this technology go?

**Giorgio Anania:** It's a trade-off. The more concentrated they are and the taller they are the more surface area you have. But you also have more difficulties in extracting light. The farther away they are, the much more light output you'll get. But you lose surface area. So the question is, where's the optimum?

**LED professional:** Would it be possible to get the same amount of light out of a smaller LED die? This would be especially advantageous for applications like spotlighting!

**Giorgio Anania:** There are some markets that are very sensitive to that. Automotive applications that are looking for higher brightness are an example. Here it's important to get more light from the same surface.

**LED professional:** What about colored light or CCT tunable light?

**Giorgio Anania:** In 2D the shift to red is done with indium. But the amount of indium is limited with the 2D technology. So you can't get GaN emitting in the red. For this, you have to go to other materials. In the case of microwires and nanowires there's the possibility to put in more indium with all the possibilities of having GaN emitting in blue, yellow, green or red. With 2D you just do the blue and combine it with the phosphors.

**LED professional:** Is this process done on a wafer level or on a microwire level?

**Giorgio Anania:** One nanowire could have 10% indium and it emits yellow whereas another one has 20% indium and emits orange. The question is; how can you have a certain number of nanowires absorbing 20% of the indium and other nanowires absorbing 15% and yet another set of nanowires absorbing 20% of the indium on one chip giving you the distribution that you want, so you can simulate a black body emission, for example?

With 2D the doping determines the emission and you don't have a lot of possibilities to change the blue.
With 3D you can actually generate a different population of colors on the same LED die. This new feature is not our first target because we want to deliver a low-cost solution first.
Once we get the blue under control we will work on the colors.

**LED professional:** How about the market roadmap for this 3D technology?

**Giorgio Anania:** The prototypes will be available at the beginning of next year. The first products will be qualified in the second half of 2014 and will be available in 2015.

**LED professional:** What kind of product levels will you offer?

**Giorgio Anania:** We will sell packaged LEDs. We will do the nanowires growth inside and organize packaging with subcontractors. We are looking for

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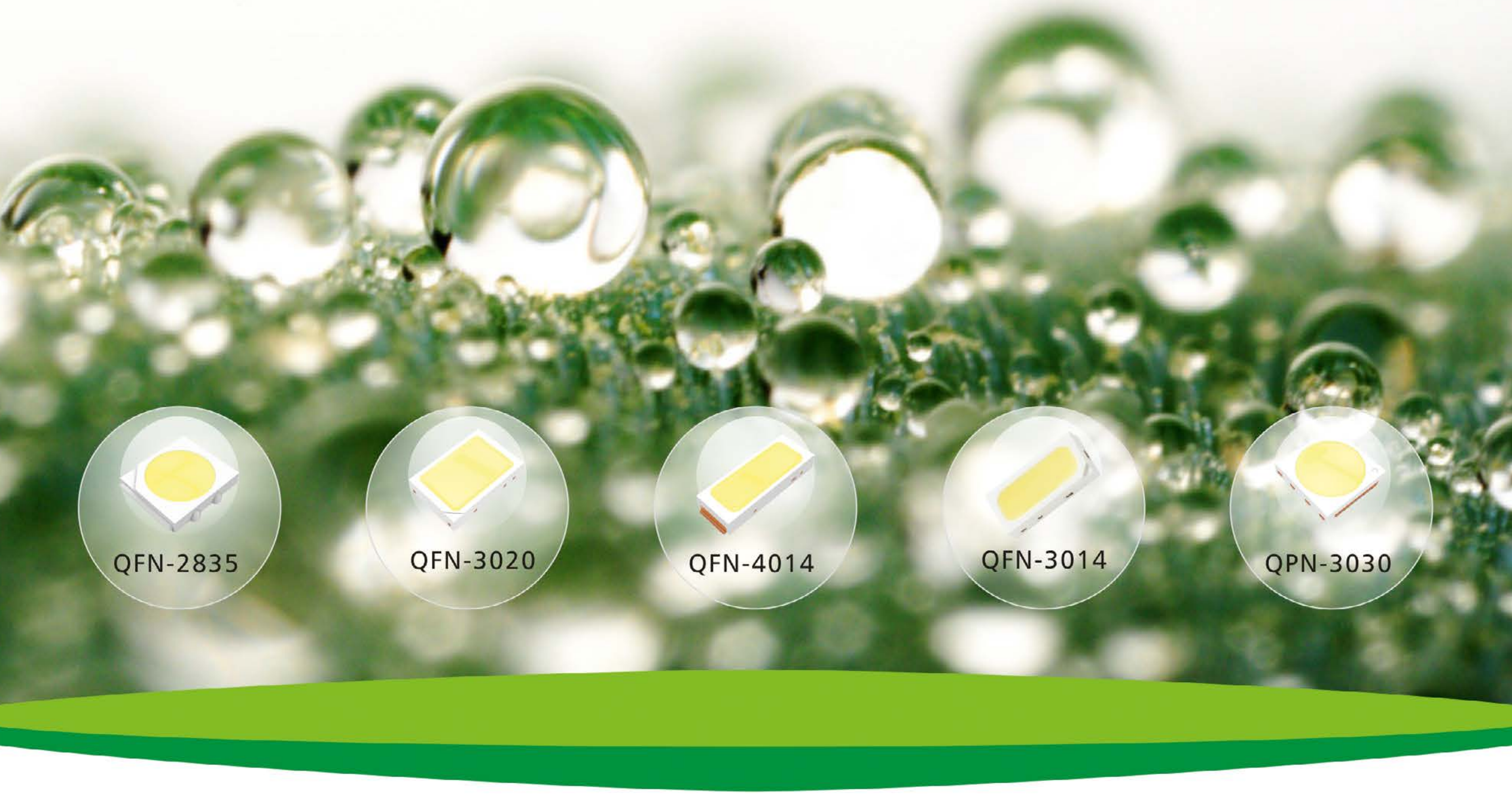


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## Giorgio Anania

Giorgio Anania is co-founder, president and CEO. He has spent more than 30 years in senior management at high-technology companies, from start-up ventures to international public companies, and has led two successful IPOs. He is chairman of Cube Optics AG and vice president of the executive board at Photonics21. Previously, Giorgio was CEO of Bookham, now Oclaro, which he grew from a start-up into a quarter-billion-dollar NASDAQ-listed public company. He also served as the vice president of sales, finance and business development for Flamel Technologies. Prior to that, he was the founder and general manager of the Miniplex DSL Business Unit at Raychem and strategy consultant at Booz Allen. He has a M.A. degree in physics from Oxford University and a Ph.D. in thermonuclear fusion from Princeton University.

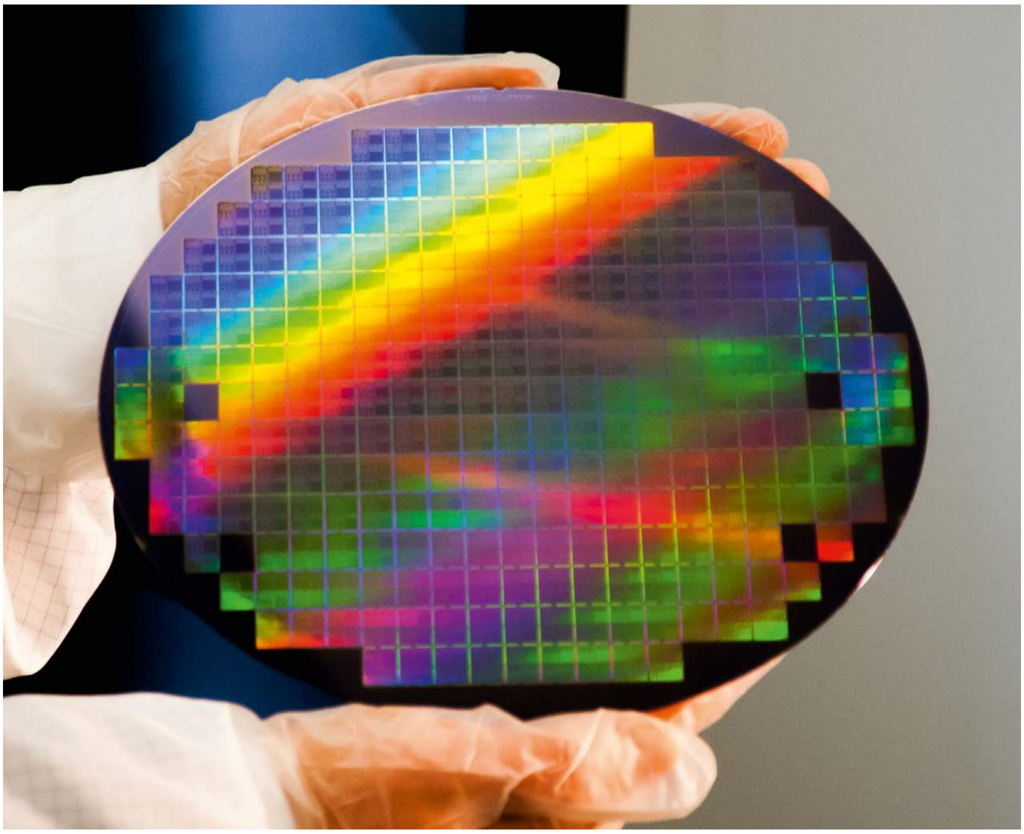

**Figure 3: One of the major advantages of this 3D technology is that big Si-wafers like this 200mm wafer can be used and stress due to lattice mismatch is minimized**

traditional packaging approaches “me-too” would be available at a lower cost. We also have a lot more opportunities when processing 8 or 12-inch wafers.

**LED professional:** Do you have plans for licensing your technology to others?

**Giorgio Anania:** You cross the road when you get there. The basic structure of our company is a manufacturing entity not a licensing entity. Of course there are some markets where one player owns 90% of the world market then you may decide do a licensing deal but those are things you can only decide when the time comes. The general strategy of our company is that of an industrial manufacturing company.

**LED professional:** What are the critical things you are working on to get your technology right for the market?

**Giorgio Anania:** Our objective is to target large commodity markets. In this market you want to go with the largest customers and do a deal with them. It’s different to go through distribution networks with a vast numbers of specifiers. When it’s a commodity the price is the main thing. The 3D technology does have more parameters then the 2D technology. So it’s not an easy task to optimize those. Anyone can play around and show some good results with microwires. But to really optimize for high-volume and high-efficiency you need hundreds and hundreds of wafer-runs. There are no technology blockages or limitations such as current density, light extraction, thermal dissipation etcetera.

**LED professional:** What about your global position with microwire or nanowire LED technology approaches?

**Giorgio Anania:** There are some other players. Our approach is probably unique because it’s focused very heavily on technical decisions that aim for low cost.

**LED professional:** Thank you for this interview and all the best with your innovative technology!

**Giorgio Anania:** Thank you. ■

 

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# Contactless LED Technology

While Contactless power distribution using electromagnetic induction technology is not new, it is rarely used in an LED illumination system. Alain Guimont, an IES member and Product Specialist at HEICO lighting™, one of the few companies that designs products based on this type of an approach, explains how it works and discusses the advantages of this technology.

In 2006, when the engineering team began developing an LED illumination system, the group considered the following limitations:

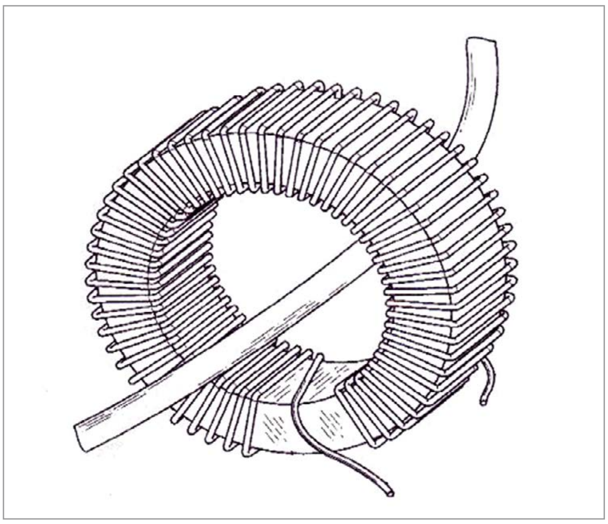
The LED modular illumination system generally used in commercial, architectural, residential or landscaping applications usually includes a DC power supply connected to 120 VAC (240 VAC). When modules do not have an integrated driver, the output of this power supply provides DC voltage to a supply rail, wire, or connectors providing electrical connection to LED arrays arranged in several illumination modules including ballast resistors (or current regulators). These modules are usually connected in parallel on a DC supply bus. The LEDs are connected with wires that are soldered permanently providing fixed electrical contacts.

The LED illumination modules are connected to one another using two to four wires mechanically creating electrical contacts. In this conventional light circuit's topology, the LED module uses a ballast resistor to provide a constant current to LEDs connected in series (since LEDs operate in current and not voltage). This dissipative method normally uses as much energy in the ballast resistor (dissipated energy) as in the LEDs, resulting in important losses of efficiency. This means there could be significant amounts of energy wasted in heat. Furthermore, the use of fixed electrical contact connectors can be prone to reliability troubles. For example, the exposure of the contact connectors to the surrounding atmosphere can cause contacts to deteriorate by chemical or electromechanical corrosion and fail prematurely. Over long distance, the illumination system comprising a power supply connected to an LED array provides non-uniform lighting since the voltage feeding the LEDs drops as a function of the distance between the LED array and the power supply.

In 2006, based on the above mentioned observations, the engineering team identified the need for an improved LED illumination system that would be reliable, simple and quick to install and that would operate at high frequency.

## Basics of the Contactless LED Technology

The Contactless LED technology, such as HEICO lighting's™ proprietary approach, is based on electromagnetic induction which is the production of energy across a conductor when it is exposed to a varying magnetic field as seen in figures 1 and 2.



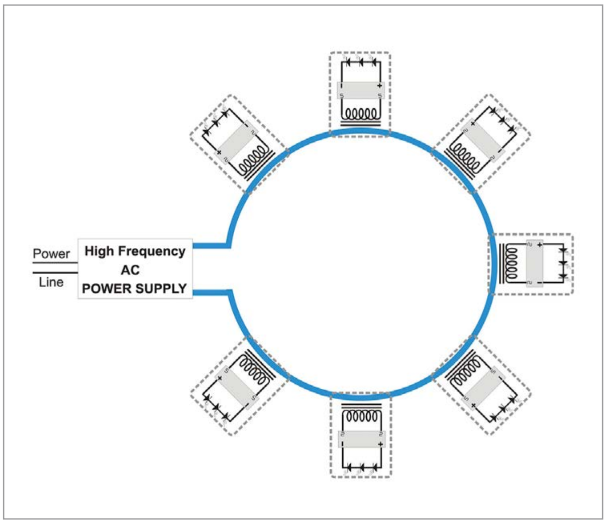



**Figure 1 (left):** Representation of the toroid ferrite - electromagnetic induction technology

**Figure 2 (right):** Contactless LED illumination system concept

The illumination system based on the Contactless LED technology comprises a power supply (AC current inverter) and a certain number of illumination modules including an electromagnetic coupling element and several lighting emitting diodes, wherein the electromagnetic coupling elements include a magnetic core arranged to receive output current from the power supply over a current-carrying loop forming a primary wire. The method includes positioning the primary wire in a close proximity to the illumination module without establishing an electrical connection, the positioning enabling inductive power transfer, as expressed in Faraday's law, from the primary wire to a secondary wire connected to provide current to one or multiple LEDs.

"Contactless" means no connectors, soldering or crimping between the LED modules and their electrical conductor. The complete system is virtually connection-free and only requires two mechanical contacts at the output of the power supply as there is no need for any other contacts anywhere else in the system. The luminaires are driven without physical contact to the source!

**Figure 3:** **Power factor for LMPS-750**

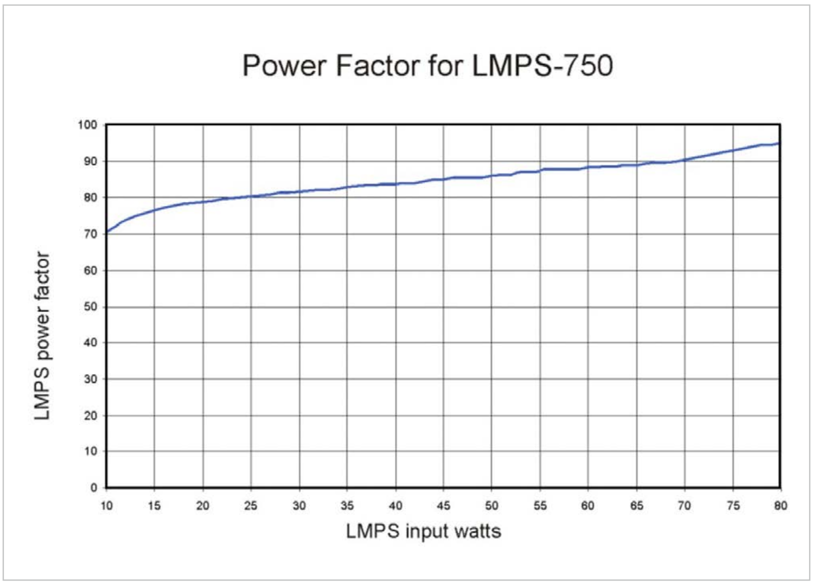
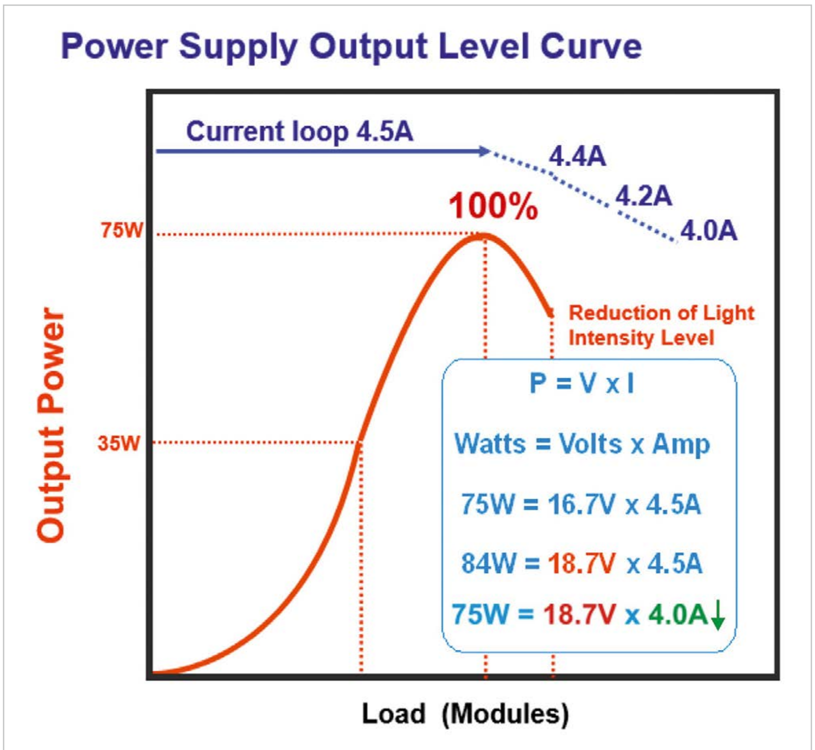



**Figure 4:** **"No shut-off" power supplies - output power behavior**




## The Power Supply Primary Side - Power Supply Features

The LED master power supply (LMPS) is constructed and arranged to transform the conventional 120 VAC to a high-frequency low-voltage electrical power provided to a primary wire forming a current carrying loop (the power supply output conductor).

All power supplies are Class 2 rated AC regulated current loop output Safety Extra Low Voltage (SELV) power supplies, but design options are similar to conventional power supplies. They may provide special features like the LMPS-750, which is an electrolytic capacitor free power supplies boasting a Mean Time Between Failure (MTBF) in excess of 50,000 hours, achieving a reliability matching that of LEDs. It is based on proprietary technology resulting in efficiency in excess of 95% as can be seen in figure 3.

### "No shut-off" power supplies

All discussed power supplies are based on a regulated current loop. Their design provides a uniform illumination of all the LEDs that are connected to the power supply.

Should an overload situation occur, for example if the wrong number of LED modules is connected to the power supply, the power supply's output current will simply be reduced automatically – the net result will be a reduction of the light intensity level and the power supply will not shut off, as can be seen in figure 4. The power supplies include an over-voltage or over-power detector. A transformer within the power supply senses the output voltage. When this voltage becomes excessive, because of overload, the main current regulating loop will be adjusted to meet Class 2 output limit and the output current will automatically be reduced to deal with overload.

## The Power Supply Secondary Side – Module Features

Within the LED illumination module, a secondary wire is wound with on a magnetic core to enable inductive coupling from the primary wire, and provide current to several light emitting diodes.

There is no need to use a ballast resistor coupled to the LEDs, since the magnetic core winding generates a true current source. Indeed, the secondary current is equal to the primary current divided by a number of turns. One could compare this topology to a parallel system. The winding acts as a parallel system and divides the voltage induced by the primary wire in several secondary coils wound around the ferrite cores.

The current induced in the secondary wire of the transformer is rectified by a diode bridge to DC to drive an array of LEDs as can be seen in figure 5.

The magnetic core may have any shape. The primary wire is threaded through an opening in the core.

The power supplies may feed a variety of illumination modules that cater to the designer needs. Modules of any size, colour or light intensity can be installed simultaneously on the same power supply and do not need to remain in a fixed position. This can be accomplished since the power supplies are based on a constant current loop and each module has its own toroid ferrite that is designed to feed off the current loop.

Within the module body, the magnetic core and the secondary wire described above are encapsulated, thereby sealing the core and wire portion while enabling displacement of the primary wire with respect to the encapsulated magnetic core. The modules are IP67 rated; they are ideally suited for indoor and outdoor applications or for applications where reliability in a wet environment is required (Figure 6).

A series of illumination modules may be controlled as a group by varying the current in the individual loops. This is achieved by employing a computerized control on each loop and allows the creation of different light effects.

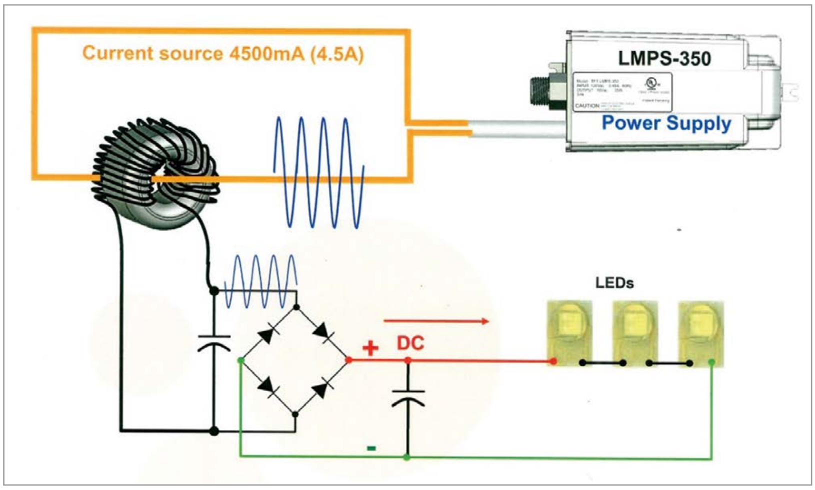



**Figure 5:** **Inside view of a contactless LED module**

**Figure 6:** **Installation in Langford fountain (Credit: Low Energy Lighting Technologies, EECOL Electric; Photo: The City of Langford)**

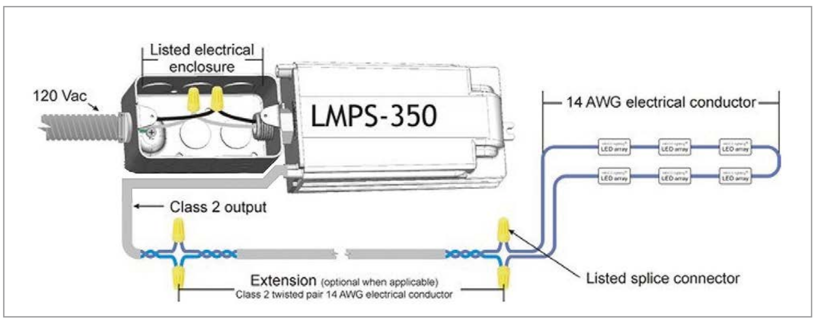



**Figure 7:** **Typical system diagram**

## Typical Configurations

There are a variety of configurations for the installation for this LED illumination system, here are two of the most typical ones:

Single wire loop with return:
Illumination modules are distributed on a long single wire and the wire comes back along the LED modules.

Twisted pair extension with single wire loop with return:
Modules are at the end of a twisted pair extension and distributed on a long single wire and the wire comes back along the modules.

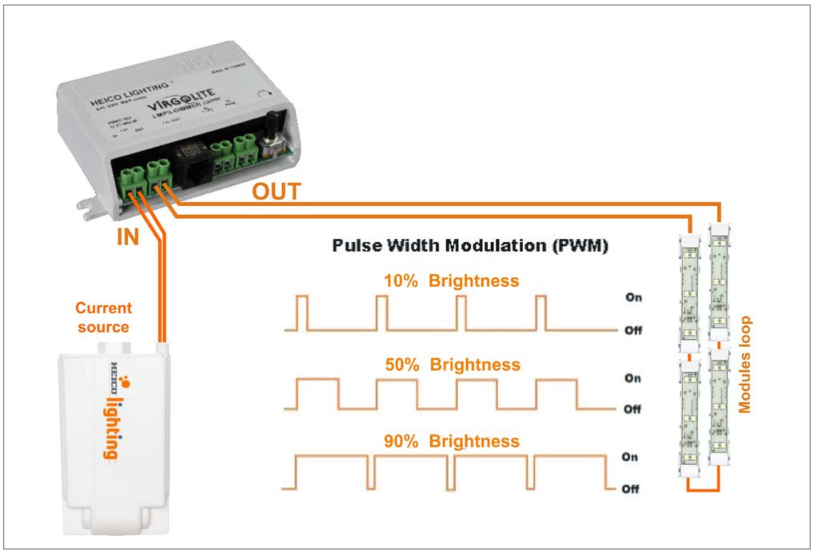
## Dimming

For dimming such a system, virtually any technology and protocol that is used in conventional installations is possible to control the dimmers. The LMPS-Dimmer Controller and a LMPS-Dimmer Extender (Figure 8) are built based on a proprietary technology.

**Figure 8 (left):** LMPS dimmer controller and LMPS dimmer extender

**Figure 9 (right):** Dimming method applied to the contactless LED illumination system


The Dimmer-Controller controls the LED illumination modules installed on the loop by using Pulse Width Modulation.

The Dimmer can be dimmed from 100% to 0% and can be controlled by any of the following methods:

- 0-10V
- PWM
- DMX protocol through a DMX Converter
- DALI protocol through a DALI Converter

## Special Application Requirements: RGB Configuration – Case Study

Case study: Langford Fountain

Description of the project:
The City of Langford, in British Columbia, Canada, wanted to revitalize the Goldstream Avenue. They planned to build a fountain, in the center of the roundabout, and create beautiful animation of lights and water jets of various intensities that would be synchronized to music. The City of Langford collaborated with EECOL Electric and Low Energy Lighting Technologies (LELTEK) to achieve this creation that included 1440 Virgo™ XS Contactless LED modules.

Installation:
All LED modules are installed in series per colour. The loops are installed one over the other.
The system is controlled by DMX protocol. Thus, all LMPS-350 power supplies are connected in series to the LMPS-Dimmer Controller and then to a 0-10V DMX converter.
The LMPS-Dimmer controller is compatible with third party DMX controllers. Both (0-10 volts and PWM) external inputs are DMX512 compatible with the proper decoder.

Connection diagram:
As per the above connection diagram, the entire project has four loops of Contactless LED modules. Each loop is connected to an LMPS-Dimmer Controller which is connected to a DMX converter.

## Advantages of an LED Illumination System Powered by Induction

The fact there is no need to establish electrical contact to any of the illumination modules results in increased reliability, lower cost, installation flexibility and extra safe operation.

The installation is very easy as there is only one wire used for powering the illumination modules and there is no polarity requirement since the technology is based on using alternative current provided by the master power supply.

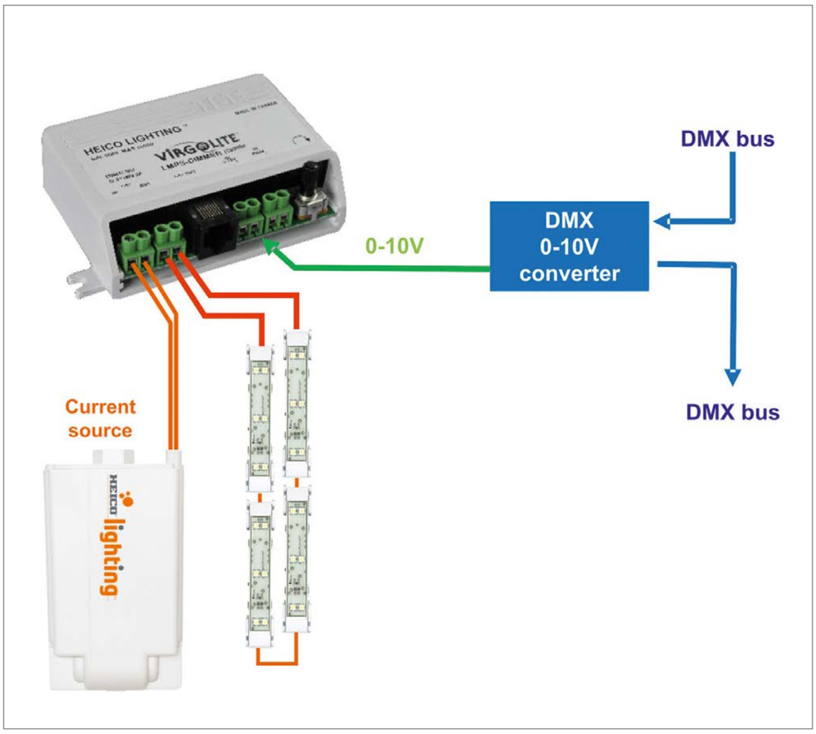



**Figure 10:** Connection diagram of Langford Fountain RGB illumination concept

The power supplies have no shut off condition and their reliability matches that of the LEDs.

For outdoor applications, modules cannot corrode since there are no connections, hence no contact points that could corrode. In addition, the modules are encapsulated, further removing the risk of corrosion. In theory, a sinusoidal current (alternating current) affect the oxidation-reduction reaction (chemical reaction resulting in a transfer of electrons) causing corrosion by limiting the mass transfer of the substance in question to zero. In the case of a metal with DC current, several types of corrosions may occur such as atmospheric corrosion, chemical corrosion and galvanic corrosion. Thus, since only the AC portion of an LED system powered by induction is fully encapsulated and an oxidation reaction is not possible in this case (especially since there is no contact of the loop) it is chemically impossible to see the corrosion damage on this type of system.

A system of this aspect has also high efficiency (low power consumption).

## System Efficiency

One of the key advantages of the Contactless LED technology is its efficiency at a very competitive price level.

The induction technology provides an extremely efficient usage of power since the only loss in the module circuitry is the one resulting from the rectification bridge in series with the LEDs. Inductive power transfer increases the efficiency of the module circuitry (which can be as high as 95% - depending on the selected LEDs) obtained from the input power for the light source to produce light.

The efficiency of the LED induction technology, coupled with the smart power supply design, yields an electrical efficiency in excess of 90% for the entire system

Under normal operating conditions, the efficacy of the LED modules varies from 75 lm/W to 110 lm/W depending on the colour and the intensity of the selected module.

# The Challenge of Designing Safer LED Lighting Products

John Showell, Product Safety Consultant at Product Approvals Ltd, considers the health and safety issues related to the current main classes of regulations affecting LED lighting. He then focuses on the highest risk product safety factors; presenting some strategies and methods for designing safer LED lighting products. The challenge of designing LED lighting products that present essentially zero risk of fire and electric shock over their lifetime is raised.

It is important to remember the most fundamental safety related considerations when designing any new product that derives its power from an electrical source, whether that source be from mains grid power, or some kind of off-line supply such as a battery or group of batteries such as for an emergency lighting system. In this article the general term "safety" will be used to represent electrical product safety as the scope of this article does not cover other fields of safety such as photo biological safety considerations.

It is proposed that electrical product safety must be the uppermost consideration when considering the wide range of regulations which affect LED lighting products nowadays. This is simply because the main hazards related to electrical products - fire and electric shock - can and do, tragically, cause fatalities - resulting from products that could potentially contain a design flaw, a manufacturing defect (a "latent" defect as we will assume that 'patent' defects are detected in the manufacturing process); or could be the result of an application error, oversight or misuse.

## UK Electrical Safety Council Report

A report by the UK's Electrical Safety Council stated that in 2010/11 in the UK there were 20,284 fires of electrical origin resulting in 48 deaths and 3,324 injuries – the majority caused by products and the remainder by installations. Referring to table 1, lighting was ranked 4th by product category as a cause of fires resulting in 930 fires, 97 injuries and 7 deaths. Defective lighting products and installations cause considerably fewer fires, deaths and injuries than other product types, but it is still an unacceptable state of affairs. LED products and installations are still in the minority but are growing rapidly. We must achieve the goal of zero fire and shock injuries and deaths as we also strive to maximise lumens per watt.

## Other Regulations and Hazards

Injuries caused by excessive optical radiation could of course be very serious and must be prevented by competent product design and application. However death or severe injury occurring from excessive non-coherent optical radiation from general lighting would only likely occur as a secondary consequence of some event such as temporary blinding from a light source, causing someone to trip over an obstacle or some other such misfortune.

Other regulations address electro-magnetic emissions and immunity and in most scenarios, the consequences of not complying with legal requirements are essentially nuisance events such as improper operation of equipment and devices in the vicinity of the offending piece of equipment. Even here, of course, one cannot rule out a fatal or serious injury because of an EMC (electro-magnetic compatibility) related malfunction although it is very unlikely.

Environmental regulations come into the category of being a lowest risk short term health hazard for an individual but of course there could be serious longer term health related problems that could occur, for example, due to contamination of a community's water supplies from industrial waste products, chemicals or substances.

**Table 1: Major products involved in electrical fires in 2010/11**

| Product [1] | Fires | Injuries | Deaths |
|---|---|---|---|
| Cooking appliances | 14,005 | 2,960 | 11 |
| Electricity supply - Wiring, cabling, plugs | 3,380 | 314 | 8 |
| Washing Machines and Tumble Dryers | 1,552 | 74 | 2 |
| Lighting | 930 | 97 | 7 |
| Fridge/ Freezer | 312 | 110 | 4 |

Energy efficiency regulations are classed in the arena of environmental regulations and legislation and of course the high energy efficiency of LED lighting is a major factor in the rapid market penetration of solid state lighting. Yet again, a health related factor can be associated with this class of regulations. Because of the prevalence of fossil fuel power generation around the world, if we can reduce energy consumption related to lighting then we will see reduced emissions of airborne pollution and this will benefit people's health. Are there any important regulations that do not have some kind of bearing on human health? Perhaps not, certainly in the key classes of regulations discussed briefly here, they all have some level of potential impact.

Returning to the subject of electrical product safety, the focus of this article, and the area that we can see is most capable of causing rapid or instant serious or fatal injury (instant in the case of an electric shock for example) the article reviews strategies and methodologies to help achieve lighting product designs that will, hopefully, never cause an injury or fatality. A product design that causes zero injury must be the goal. How will you ensure your design and product causes zero injuries over its entire lifetime?

Designers of lighting products may create products that are actually, in themselves, not capable of causing a fire or an electric shock. In this regard the type of product in mind is one that is powered from an energy source that is considered incapable of causing such an event because of its inherently limited available energy - specifically an energy source that is limited as to the electrical current availability, and to the maximum voltage that could be exposed to the human. Consequently, we have the first strategy that could help a product designer create a lighting product that cannot create a fire or electric shock - use of a 'safe' power source.

## "Safe" Power Sources

An obvious 'safe' power source is the source created by putting some batteries into an LED flashlight - clearly there is a limited maximum voltage and zero risk of electric shock, and equally there is only a finite maximum current available in a small battery powered product. People tend to think of small batteries as safe power sources and mostly, they will be. Whilst there may be zero risk of electric shock in the example of the flashlight, we could conceive that under a fault condition, it may be possible to achieve a current level high enough to cause a fire. Admittedly, it is highly unlikely - we only tend to hear of fires caused by higher capacity battery sources such as some publicised cases of fires occurring with laptop computer batteries or some incidents with electric vehicles and so on. The factors in defining a safe power source soon become complex so we mostly rely on the body of evidence generated from research in various regions of the world, resulting in published guidance as to what constitutes a power source that presents no risk of fire or shock. Further, we may go to the trouble of performing tests that give us confidence that a fire or shock risk does not exist under any reasonably foreseeable condition (most typically in the world of safety assessment that means consideration and analysis of a single component or material fault occurring in the product or power source).

## US Regulations

In the USA for many common applications, there are standards which give guidance on power sources which can be considered to present no risk of fire or electric shock. Generally speaking, the product that is energised by this power source therefore needs no special evaluation or testing to verify that it cannot cause a fire or shock hazard.

NFPA 70 (more commonly known as the NEC or National Electrical Code) is the standard being that is used extensively and applied across US industry, workplaces and also in private homes and other locations. Specifically, the type of power source that is considered to present no risk of fire or shock is a 'Class 2' power supply.

Class 2 inherently limited power supplies are power-limited to 100 VA and have a maximum output voltage of 42.4 $V_{peak}$. This is not exceeded under any single component fault condition in the power supply, such as the failure of a component in the switched mode power supply regulation circuit, if that topology is used. Definitions can be found in NEC (2011) Article 725 part III.

Another useful standard for the USA is UL1310 standard for safety - 'Class 2 Power Units'. This is a full end-product standard and certain UL1310 agency Listed Class 2 power supplies can be purchased and / or specified for use as a "safe" power source, thus removing the fire and shock hazard analysis from the connected load. It is important to understand the two main categories of UL1310 power supplies - inherently limited and non-inherently limited (definitions in clauses 30.2 & 30.3 respectively of UL1310). Only inherently limited power sources meet the 'safe' level without further

**Table 2: The US National Electrical Code – Class 2 inherently limited – no further protection required**

| NEC Class 2 - Overcurrent Protection Not Required | | | |
|---|---|---|---|
| Source Voltage Vmax (Note 1) | Power Limitations VAmax | Current Limitations Imax | Maximum Overcurrent Protection |
| Up to and including 20 $V_{ac}$ | - | 8 A | - |
| From over 20 to 30 $V_{ac}$ | - | 8 A | - |
| From over 30 to 150 $V_{ac}$ | - | 0.005 A | - |
| Up to and including 20 $V_{dc}$ | - | 8 A | - |
| From over 20 to 30 $V_{dc}$ | - | 8 A | - |
| From over 30 to 60 $V_{dc}$ | - | 150 / $V_{max}$ | - |
| From over 60 to 150 $V_{dc}$ | - | 0.005 A | - |

Note 1: Voltage ranges shown are for indoor locations or where wet contact is not likely to occur

**Table 3:** **The US National Electrical Code – Class 2 non-inherently limited – additional protection required (such as external fusing)**

| NEC Class 2 - Overcurrent Protection Required | | | |
|---|---|---|---|
| Source Voltage Vmax (Note 1) | Power Limitations $VA_{max}$ | Current Limitations ($I_{max}$ = Const/$V_{max}$) | Maximum Overcurrent Protection |
| Up to and including 20 $V_{ac}$ | 250 VA (Note 2) | = 1000 / $V_{max}$ | 5 A |
| From over 20 to 30 $V_{ac}$ | 250 VA | = 1000 / $V_{max}$ | = 100 / $V_{max}$ |
| Up to and including 20 $V_{dc}$ | 250 VA (Note 2) | = 1000 / $V_{max}$ | 5 A |
| From over 20 to 60 $V_{dc}$ | 250 VA | = 1000 / $V_{max}$ | = 100 / $V_{max}$ |
| Note 1: Voltage ranges shown are for indoor locations or where wet contact is not likely to occur | | | |
| Note 2: If the power source is a transformer, $VA_{max}$ is 350 or less when $V_{max}$ is 15 or less | | | |

measures (outputting up to 42.4 $V_{pea}$ or 60 $V_{dc}$, and with a maximum current output up to 8 Amps).

Coming down to the UL8750 standard for safety – "Light Emitting Diode (LED) Equipment for Use in Lighting Products" we see there are references to UL1310 Class 2 power units and a LED luminaire evaluated to UL8750 would meet the requirements of UL8750 if it incorporated a Class 2 or equivalent power source without further special evaluation. Note that UL8750 could be applied to a complete piece of LED lighting equipment if the application for that equipment is not covered by an existing UL standard such as UL48 for Electric Signs or UL1574 Track Lighting Systems. Clause 1.3 of UL8750 lists such end application / product standards and if the LED equipment comes under one such standard, it would be evaluated by an agency to the application standard requirements such as UL1574 & UL8750.

In additional to constructional analysis such as verification of electrical spacings (creepage and clearance) and insulating barriers, UL8750 addresses analysis of electric shock and fire hazards by clause 8.5 abnormal tests which include component failure testing and output loading. Other tests may be necessary. A decision must be made at the outset of a new project as to the main strategy to be adopted to prevent risk of electric shock:

Use of an inherently safe power source such as a Class 2 UL1310 or UL60950-1 ITE (Information Technology Equipment) agency certified ('Listed' by a US OSHA-accredited Nationally Recognized Testing Laboratory) power source.

Use of the common principles of protective separation of hazards from users:

- Insulation by use of physical insulation barriers which can provide the entire protection (referred to as double or reinforced insulation), or partial protection supplemented by air gaps or over-the-surface insulation
- Insulation by use of spacings - by through - air (clearance) or over - surface (creepage) distances
- Insulation using a single barrier - basic insulation - plus earth bonding

In applying one of these strategies to achieve prevention of electric shock, one must consider the ability of the solution to continue to provide the required protection in the application over at least the envisaged service life, plus a safety margin. LED drivers are now being advertised for sale with expected lifetimes of 20+ years. One insulation type that will not degrade over time is of course the 'insulation' provided by air (i.e. 'clearance') which is renewable. It's 'counterpart' often used in many designs – 'creepage' (over-the-surface spacing) – will degrade for most materials though, either because of gradual electrical tracking over the surface of the insulating material and possible ultimate breakdown (even potentially causing a fire), and/or due to build-up of pollution on the material surface. This latter degradation mechanism assumes that a PCB for example is not contained in a sealed enclosure, or encapsulated by conformal coating (which itself will have a certain maximum service length).

Solid insulation will often be used but this is susceptible to partial discharging and possible ultimate breakdown of the insulation. Special consideration should be given to so called 'solid' insulation in constructions such as the inner layers of a PCB which may contain multiple voids resulting from the manufacturing process so a margin of safety over the minimum figure stated in applicable standards should be used. PCB delamination risk should also be considered and this could cause loss of adequate insulation between an inner layer track near the edge of a PCB and an adjacent earthed metal enclosure for example.

It is a good idea to draw an insulation diagram such as the one below to record how the separation between humans and hazardous voltage circuits will be achieved.

## EU Regulations

SELV (Safe Extra Low Voltage) levels are the equivalent to the US NEC / UL1310 Class 2 maximum safe-to-touch voltages.

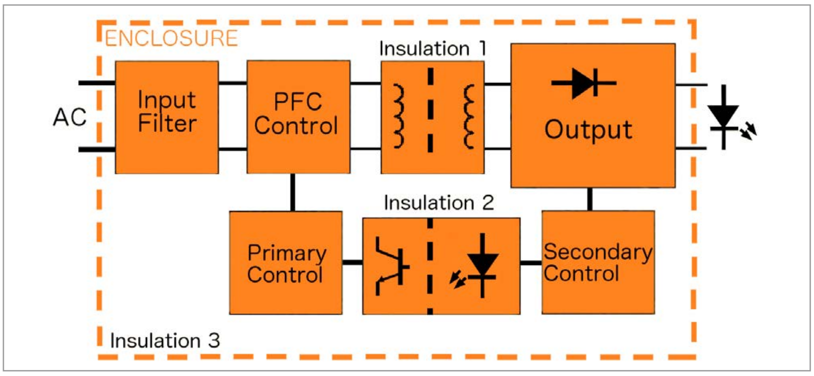



**Figure 1:** **Insulation diagram showing internal and external isolation barriers for a simple LED driver – consider what barriers will be implemented as solid insulation, basic, supplementary or grounded, and whether part of the insulation system may reside in the LED light module for example**

**Table 4:** **Currently published key LED related safety standards. Note UL 8750 current version is first edition November 18, 2009 with revisions through October 17, 2012**

| Area of Application | EN/IEC Standards | UL Standards* |
|---|---|---|
| LED modules with and without control gear | EN/IEC 62031:2008 | UL 8750** |
| Separate LED control gear | EN/IEC 61347-2-13:2006 | UL 8750** |
| LED modules with control gear and a lamp cap | EN 60968:2013<br>IEC 60968:2012 | UL 8750** |
| Connection Systems for LED modules | EN/IEC 60838-2-2:2006+A1: 2012 | UL 8750** |
| LED self-ballasted lamps ( >50 V) | EN 62560:2012***<br>IEC 62560:2011 | UL 8750** |

* UL 8750 references many other UL Standards
** UL First Edition from 18th November 2009, ANSI Approved
*** The standard is published and for now not mandatory by the OJ of the EU

Note that ELV circuits are not safe to touch because they only have one level of insulation between them and hazardous voltage circuit and there is an un-acceptable electric shock risk if this one barrier fails. In SELV circuits, there is an additional barrier.

Increasingly, there is harmonisation in the standards world and the definitions of safe power sources should increasingly become harmonised across the world. Where there is an IEC safety standard for a particular product type then this is already well advanced. More and more standards in the EU, North America and elsewhere are being derived from the IEC standard, typically with identical base text plus some additional specific national deviations.

## EU definition of "safe" power sources

As mentioned, many EU standards now are derived from the recognised IEC standard. For safety in the EU, all LED product types, one should turn to the Official Journal of the EU relating to the Low Voltage Directive 2006/95/EC (which can be accessed via website ec.europa.eu) in order to try to identify a suitable harmonised standard. Conformance to the relevant harmonised standard(s) will give a presumption of conformity to the Low Voltage Directive. The official journal (OJ) lists the standards which have been harmonised under the Low Voltage Directive.

A similar approach could be taken to that described for the US regulations - that is to say choose to contain the hazardous circuits and possible fire source inside a separate power supply thus allowing the LED module or luminaire designer free to concentrate on the light producing part of the design without the burden of much work on analysing and creating the safety case for the power source.

The type of power supply / LED driver needed in Europe for this approach is the SELV type.

A reference to "SELV operated LED modules" can be found in EN 62031 LED modules for general lighting - safety specifications although no definition of SELV is found in this standard. We can however consult EN 60598-1 (Luminaires – general requirements and tests) and SELV is defined as safety extra low voltage in clause 1.2.42.2 of that standard. SELV circuits have double or reinforced insulation between them and hazardous voltage circuits and so are safe to touch and require no insulation. According to EN 60598-1 clause 8.2.3c), an exposed circuit under load must not exceed 25 $V_{rms}$ or 60 V ripple free DC, so at least in DC voltage terms, we see some basic commonality here with the US maximum voltage under UL1310 Class 2 power units. However the SELV definition in the above clause goes on to mention allowable exposed voltages in excess of 25 $V_{rms}$ / 60 $V_{dc}$ but with touch current limits of 0,7 mA (peak) and 2,0 mA for DC. Further, the no-load voltage should not exceed 35 $V_{peak}$ or 60 $V_{dc}$ ripple free (so the excursion above 60 $V_{dc}$ is only allowed under the loaded condition with the imposed touch current limits). These limits are derived from IEC 60364-4-41 Low-voltage electrical installations - Part 4-41: Protection for safety - protection against electric shock.

Clearly the LED product designer potentially has a lot of extra safety related methodology, planning, design, testing and verification work to do if a custom-designed power source is specified for the product. The budget for the project should allow appropriate extra development time and cost plus further costs when it comes to possible third-party test and certification of the overall product.

Simply specifying and incorporating an off-the-shelf 'safe' power source is not quite enough, of course. Due diligence must be done to gauge the quality and safety of the bought-in unit, especially if it has not been third-party agency certified.

Finally, in this brief discussion of higher level safety considerations, we come to the EU approach on fire hazard of the power source. There is not a simple equivalent to the US Class 2 current / power limit which in that regulatory scheme has the meaning of not being able to cause a fire. So we must take the approach of analysing the fire risk from the point of view of construction, component and material selection, and testing. This is all necessary for custom designs assessed in accordance with US safety regulations and the safety parameters (such as comparative tracking index, hot wire ignition performance) are similar. However, we don't have the exact equivalent to the US Class 2 inherently limited power source definition. An EU SELV specification power source is a halfway house (we can buy a power source that won't cause an electric shock hazard) but work would be needed to show that it cannot cause a fire.

## Conclusion

For products destined to be sold into the North American market, it is possible to select a bought-in power supply that provides a 'safe' source of power that is standards compliant (Listed by a US Nationally Recognized Testing Laboratory) and leaves the designer free to concentrate on the other aspects of the LED product design - providing the 100 VA power limit of the inherently limited power source is sufficient for the application (multiple Class 2 power supplies could be used for more LED modules or luminaires - but they must not be connected in parallel or the Class 2 status will be lost).

For the European situation (and several other countries due to the armonisation between EN and IEC standards), we can get a halfway house 'off-the-shelf' safe power source in the form of an SELV rated and certified power supply, which will prevent an electric shock risk being passed into the LED module or luminaire circuit thus potentially eliminating a lot of extra design work.
But we must pay special attention to designing and testing to verify that the SELV source cannot create a fire hazard.

If we cannot use a Class 2 / SELV safe power source, then we must allow significant extra time and thus financial budget in the product development stage to assess and verify the safety of the power source and load circuits. We should also devise the high-level safety case approach as to how a design will be implemented to achieve the goal of zero injuries being caused during the lifetime of the LED module / luminaire. Drawing the first version of the electrical isolation diagram is a good first step to achieving a safe yet cost effective design solution that will also allow safety to be easily assured and verified once in production.

**References:**

[1] UK Electrical Safety Council. Statistics, core data set. http://Www.esc.org.uk/stakeholder/policies-and-research/statistics/
[2] US National Fire Prevention Association, standard no. 70 – US National Electrical Code, 2011.
[3] Underwriters Laboratories UL1310 standard – Class 2 power units
[4] Underwriters Laboratories UL8750 standard – Light Emitting Diode (LED) Equipment for Use in Lighting Products
[5] IEC / EN 62031 standard LED modules for general lighting – safety specifications
[6] EN 60598-1 standard – Luminaires – general requirements and tests



# Reliability Oriented Design of LED-Based Light Sources

The transition from traditional light sources to SSL systems requires a different design philosophy to achieve the advantages offered by LED light sources. The key approach is based on the parallel design of thermal, electrical, optical and spectral properties of the light source. Matteo Meneghini, Gaudenzio Meneghesso, Enrico Zanoni and Matteo Dal Lago from the Department of Information Engineering at the University of Padova, and Nicola Trivellin from LightCube SRL explain this approach including the importance of the electrical management of LEDs, comparing modulation techniques to constant current, differentiating between versatility and efficiency.

The performance of LED-based light sources is increasing day-by-day, thanks to the continuous efforts of manufacturers and researchers on the developments of this technology. As a consequence, solid-state light sources have higher efficiency and similar color rendering compared to conventional light sources, and have costs that are rapidly decreasing as the market penetration increases. Despite the excellent characteristics of modern power LEDs, several factors complicate the development of robust and efficient LED-based light sources, including a non-trivial thermal management, problems related to chemical compatibility, the need of designing suitable optical and mechanical design, and developing efficient electrical configurations.

This paper analyzes the major issues related to the design of reliable LED-based light sources, by giving an overview of the most important aspects and most advanced techniques required to ensure long-lasting performances of these innovative light sources.

## Thermal Evaluation

The thermal management is probably the most important issue related to the development of a reliable solid-state light source. In fact, with a non-adequate heat dissipation, the LED modules can reach extremely high temperature levels which dramatically reduce the luminaire lifetime: every single interface in the thermal path between the active area of the LED and the environment can act as a bottleneck for the heat flow, and then an extremely accurate thermal evaluation is imperative in the luminaire design process.

In the following we describe the most common methods that allow one to characterize the thermal behavior of a light source. The most basic technique is to measure the temperature of the various luminaire parts during operation, through a thermocouple or other type of temperature sensors (e.g. NTC thermistors). This procedure does not extract the temperature reached by the LED junction, but provides information on the temperature reached by the board during operation. For this reason, this method is convenient only for a qualitative evaluation of the self-heating of the devices.

A more accurate thermal characterization can be carried out by means of an infrared camera: the IR camera imaging instantaneously provides several data on the heat distribution across a circuit board or over the lamp body. Figure 1 shows an example of an IR image of a solid-state lamp, where it is clearly visible the heat

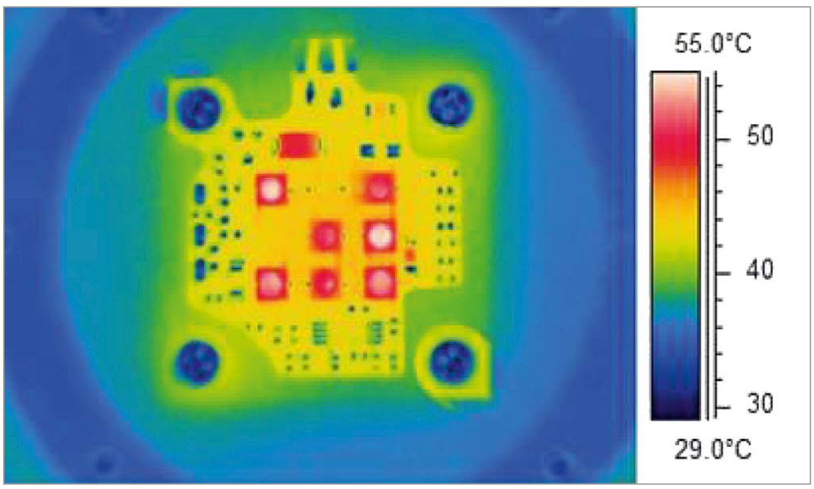



**Figure 1:** **IR image of a LED board during operation**

distribution near some of the LEDs and the driving circuitry. The IR camera is extremely useful for understanding the thermal behavior of the whole lighting system and to identify potential criticalities of the design. The main disadvantage of this technique is related to the different materials of which a LED lamp is constituted: in fact, the various metal and plastic materials have different infrared emissivity values, and – for this reason - it is difficult to compare the temperature levels measured with the IR camera on different materials. Another limit of IR imaging is that the camera detects the infrared emission of the surface of these devices, which – in general – does not correspond to the temperature levels reached by the junction of the LEDs: for example, the IR measurement carried out on an LED gives information about the temperature reached by the plastic lens that covers it, and not on the temperature level of the active area of the LED itself.

Since it is not possible to directly measure the temperature reached by the junction, the only way to fully characterize the thermal behavior of a lighting system is to use indirect electrical measurements. It is well known that the forward voltage of an LED is strictly related to its temperature. For this reason it is possible to use the forward voltage information to accurately estimate the temperature reached by the chip during operation. In order to establish the relation between the forward voltage and the junction temperature it is necessary to submit the LED to current pulses while varying its temperature by mean of a temperature chamber or a Peltier-cell. The duration of these current pulses must be considerably short in order to avoid a significant self-heating of the device. In the left side of figure 2 is reported one example of this calibration measurement carried out on an LED in a temperature range from 25°C to 95°C at different current levels. Once the calibration measurement is done, it is sufficient to measure the forward voltage of the device during operation to estimate its junction temperature.

Thanks to this technique it is possible to estimate the thermal resistance of one LED or of an LED cluster, which is obtainable as the slope of the linear dependence between the junction temperature reached during operation and the generated thermal power, as visible in the right side of figure 2. Although this procedure requires a complex set of measurements and is more time-consuming with respect to the IR characterization, it is the most reliable way to carry out absolute temperature and thermal resistance estimates on LED based light sources.

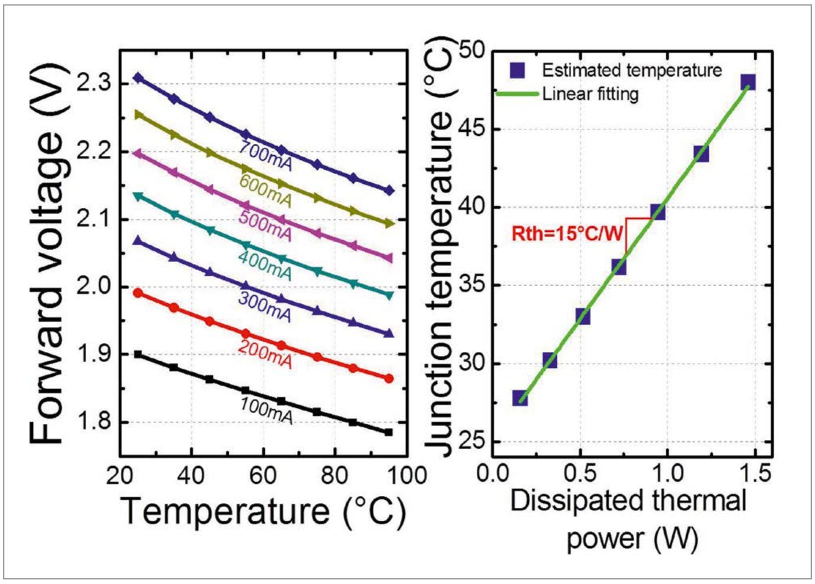



**Figure 2:** Example of a thermal calibration measurement on a power LED (left). Example of thermal resistance evaluation (right)

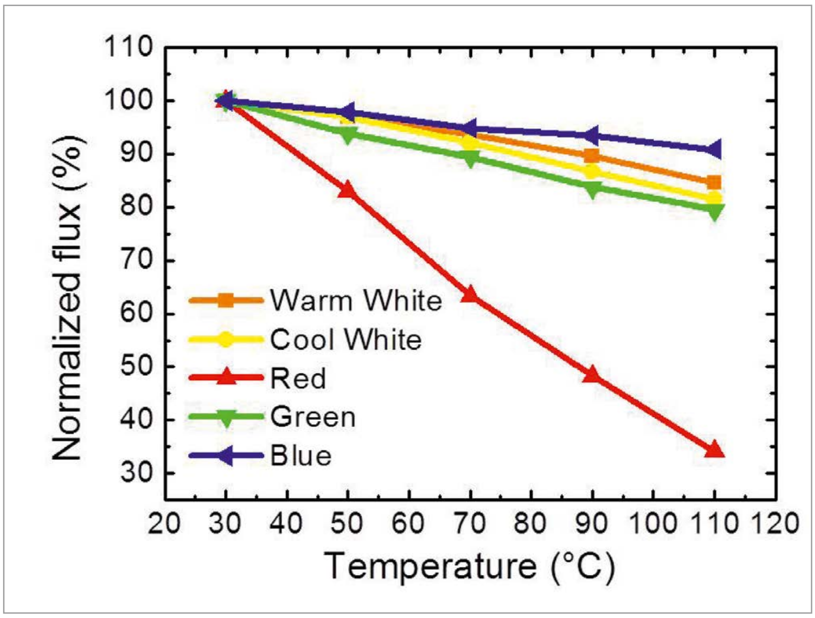



**Figure 3:** Optical power decay at different temperature levels for different colored LEDs

## Influence of the Operating Conditions on LED Performance

Despite the excellent performance of the state-of-the-art LEDs, a high-quality luminaire design cannot neglect their limits in order to exploit their full potentialities in terms of efficiency and robustness. Unlike incandescent lamps, a rise in temperature and operating current in LED based light source leads to a worsening of its electrical and optical characteristics. There are several studies that correlate the decrease of the optical efficiency at high current densities to two different physical mechanisms, one temperature-dependent ("thermal droop") and one related to the operating current (more precisely to the current density, the "efficiency droop").

Figure 3 shows the optical power decay caused by the temperature rise in different power LEDs with different

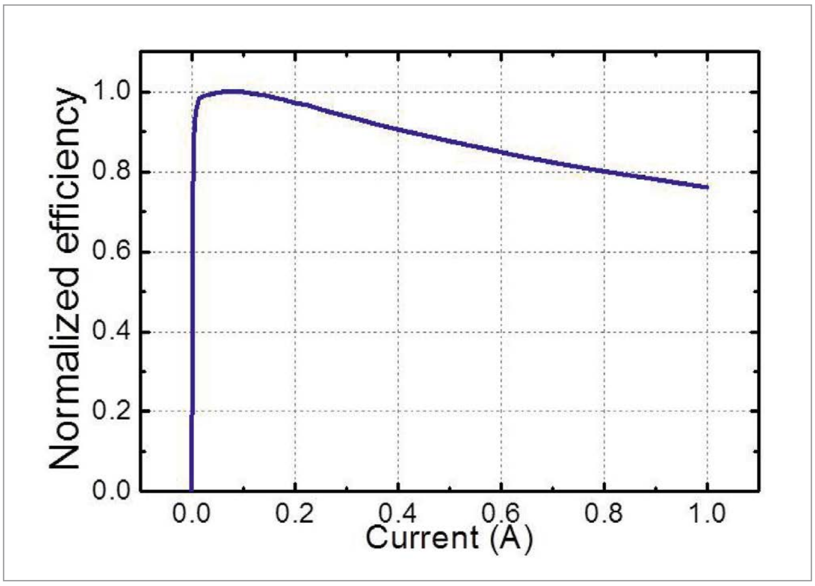



**Figure 4: Efficiency of a white power LED at different current levels**

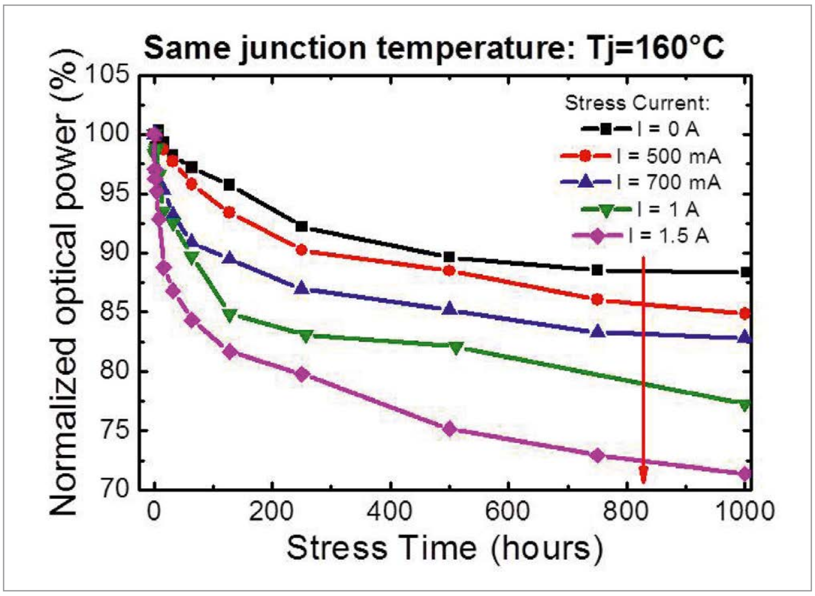



**Figure 5: Optical power degradation of white LEDs submitted to stress tests at different current levels with the same junction temperature (Tj=160°C)**

emission wavelength: this problem is significantly marked in red LEDs (due to the fact that – at high temperature levels – carriers can easily escape from the quantum wells and to an increased non-radiative recombination) and must be carefully considered when the red LEDs are used together with LEDs of other wavelengths in a multi-color light source.

On the other hand, the efficiency droop is supposed to be related to Auger recombination, and/or to carrier leakage. Auger recombination occurs mainly at high injection levels, when an electron-hole recombination transfers its energy to another electron. This excited electron loses then the acquired energy in a series of collisions with the lattice, without light emission.

As showed in [3] this type of recombination process is one of the possible causes of the current-dependent efficiency droop.

The impact of the efficiency droop on the performance of LED-based light sources is dramatic. Figure 4 shows the dependence of the efficiency on current density for a modern power-LED: this device, which can operate at current levels up to 1 A, loses the 20% of its maximum efficiency at the higher current condition. This type of information is extremely important in the design of an LED-based light source and especially for the choice of an appropriate operating current: since the efficiency is higher at lower current levels, the only way to obtain the maximum efficacy results in LED systems is to reduce the operating current with subsequent increase in the number of required LEDs.

## Operating Conditions and Reliability

The two most important factors that accelerate the degradation of a solid-state light source are temperature and current. Both high temperature and excessive current flow cause long term modifications on the physical structure of the LED die and on the packaging materials. The close correlation between these two factors implies that an appropriate operating current cannot be chosen without an accurate thermal evaluation (as described in the first section of this paper).

A high current density can cause different types of long-term modifications of the electrical properties of the chip, such as the generation of lattice defects; these modifications have important effects on the electrical behavior of the LED (i.e. I-V characteristics) but also degrade significantly its optical efficiency, as reported in figure 5 which shows the optical power decay on LEDs submitted to different current levels stress tests operating at the same junction temperature. Another important consequence of the operation at high current level is the large amount of heat generated by the device.

The high temperature levels generated by self-heating (or imposed by the environment) have serious consequences on both the electrical characteristics and the optical/mechanical properties of the whole materials of the lighting system. Regarding the electrical modifications, high temperature levels trigger several types of degradation mechanisms such as the degradation of the ohmic contacts, and also concur in the defects generation activated by the carrier flow. Exactly as the semiconductor material, also plastics and metals can be affected by the operation at high temperature. In general the plastics used for the optics and for the package,

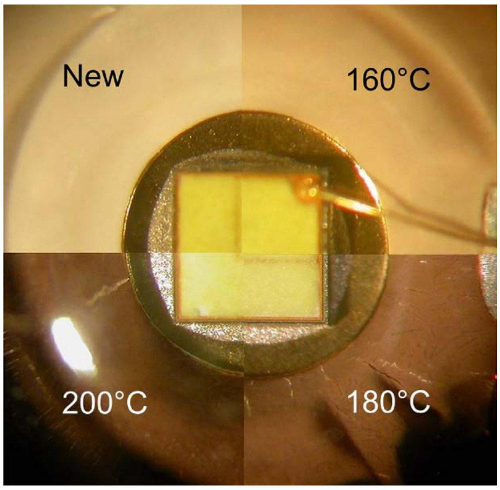



**Figure 6:** **Package browning after 64 hours of operation at different temperature levels**

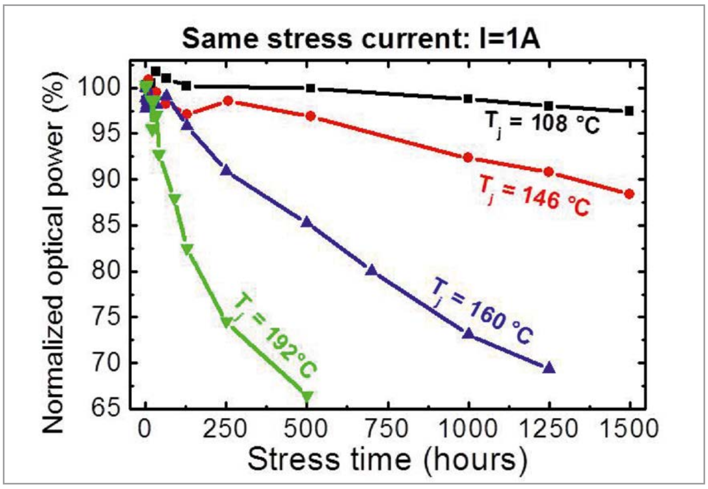



**Figure 7:** **Optical power degradation of white LEDs submitted to stress tests at different temperature levels with the same operating current (I=1A)**

can darken after some thousand hours at high temperature, as shown in figure 6 which reports an example of browning of the plastic reflector cup on a white LED. This material darkening can reduce the LED light emission of a significant part and may also lead to a variation of the colorimetric characteristics of the device.

Another problem of operating LEDs at high temperatures is related to the different mechanical expansion coefficients of the various materials that can cause the lens cracking and the detachment of the different mechanical interfaces. Figure 7 shows a comparison between four different stress tests carried out at the same current and different junction temperature.

The results of the accelerated stress tests reported in figures 5 and 7 show that, even under the limits recommended by the manufacturer, the lifetime of the modern power LEDs can be significantly reduced due to inappropriate design choices.

## Types of Failure Mechanisms

In the design of a LED-based light source, the knowledge of the effects of non-adequate operating conditions is imperative in order to fully understand the limits of the currently available technology.

Overvoltage and overcurrent events often lead to the fusion of the bonding wire that connects the chip: this phenomenon can be dramatic in an LED system where a large number of LEDs are connected in series because the failure of single LED can cause the opening of the circuit and then the complete shutdown of the luminaire.

Another type of failure mechanism can be associated to the chemical compatibility with all the substances that can interact with the LED materials: in fact there is a large set of compounds (often indicated in an specific document by the LED manufacturer) that can seriously damage the device. In figure 8 is an example of silicone lens shown that has been in contact with the soldering flux, which becomes darker after the first hours of operation. The picture of figure 9 reports the effect of the moisture penetration below the silicone lens that has caused a gradual blurring of the optical interface.

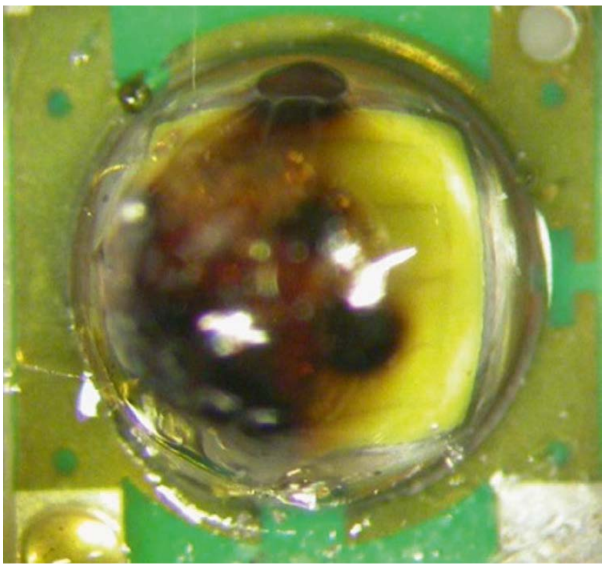


**Figure 8:** **Silicone lens contaminated with soldering flux after 24 hours of operation**

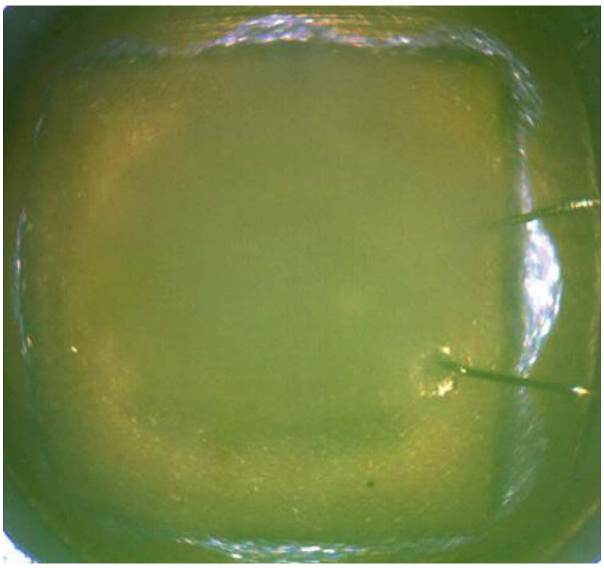
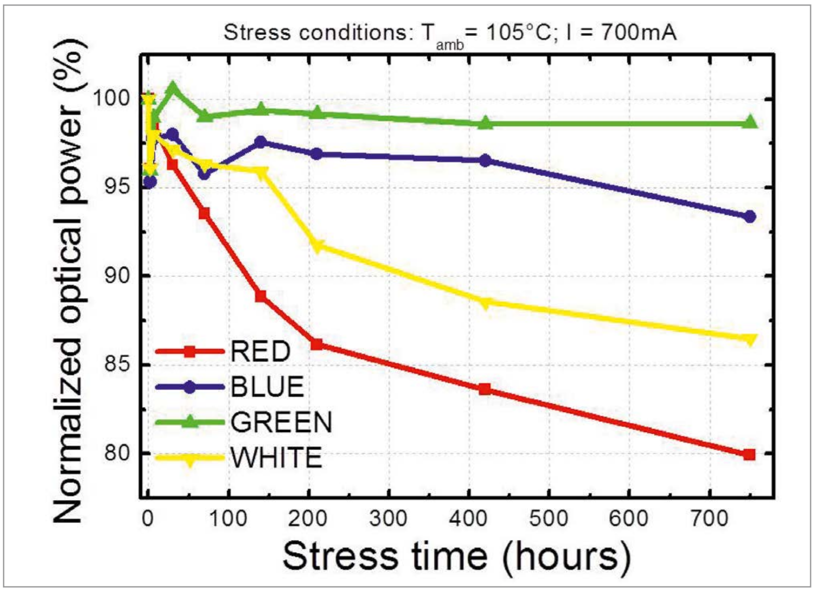


**Figure 9:** **Image of the humidity penetration effect below the lens of a white LED**

**Figure 10:**
**Optical power degradation of different colored LEDs submitted to a stress test at the same operating conditions (Tamb=105°C, I=700mA)**




These are just few examples of the problems that one may encounter when the development of a LED-based light source is not supported by an accurate assessment of all the reliability issues involved.

## Multi-LEDs Systems

One of the best ways to improve the photometric and colorimetric qualities of the solid-state light sources is to mix devices of different colors in order to enrich the emission spectrum and to increase the CRI. Multi-colors light engines allow also to dynamically changing the light characteristics according to the needs. The behavior of LEDs with different emission wavelengths in terms of robustness and performance introduces serious difficulties to the design of a multi-LEDs light source. In fact as showed in figure 3, different colors LEDs have a different drop in optical efficiency with the temperature increase. Furthermore, different types of LEDs have also different robustness to the operating condition, as highlighted by the graph of figure 10, which compare the degradation of different colors LEDs submitted to the same operating conditions. This aspect leads to the conclusion that without any type of dynamic control, the performance of a multi-LEDs lamp cannot be sufficiently stable due to the variation of the relative intensity of the various colors emissions.

The best way to avoid the colorimetric thermal drift of these types of light sources is to integrate a temperature sensor inside the LEDs circuit board. Hence it is sufficient to automatically modify, through an appropriate algorithm, the biasing configuration of the different colors LED chains according to the detected temperature during operation. However, this technique doesn't take into account the degradation of the devices during long-term operation. For this reason, in multi-LEDs lighting systems, it is often necessary to introduce a photodiode (single or multi-color) to detect and correct the variation of the colorimetric characteristics of the light source.

## Conclusions

This article has presented some of the major issues related to the design of a solid-state light source, with particular focus on the reliability aspects of the state-of-the-art LED technology. Since the LED-based light sources represent the future of lighting in all the different application areas, it is important that lighting designers broaden their knowledge on all issues that must be addressed to develop a reliable and efficient light source. Even if the technological progress leads to the production of more robust devices, some limitations will remain because they are inherently related to the LEDs functioning. Although it requires a few more steps, a reliability oriented design will lead to numerous benefits in terms of performances, maintainability and longevity and certainly it will increase the commercial attraction on the new born light sources.

**References:**

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[2] Bochkareva et al. "Defect-related tunneling mechanism of efficiency droop in III-nitride light-emitting diodes", Appl. Phys. Lett. 96, 133502 (2010)

[3] Kioupakis et al. "Indirect Auger recombination as a cause of efficiency droop in nitride light-emitting diodes", Appl. Phys. Lett. 98, 161107 (2011)


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# LED and Lens Degradation Through Volatile Organic Compounds

In general, LEDs are very resistant light sources. Nevertheless, glues, conformal coatings, o-rings, gaskets, and potting compounds, all materials that are frequently used in the construction of LED based luminaires or lamps and often contain volatile organic compounds (VOCs) may have a negative impact on performance, reliability and lifetime. Edward Steinke, application engineer at Cree, explains the set of problems and how to prevent these issues based on Cree's products, using their test kit components, as well as components for lamp and luminaire applications.

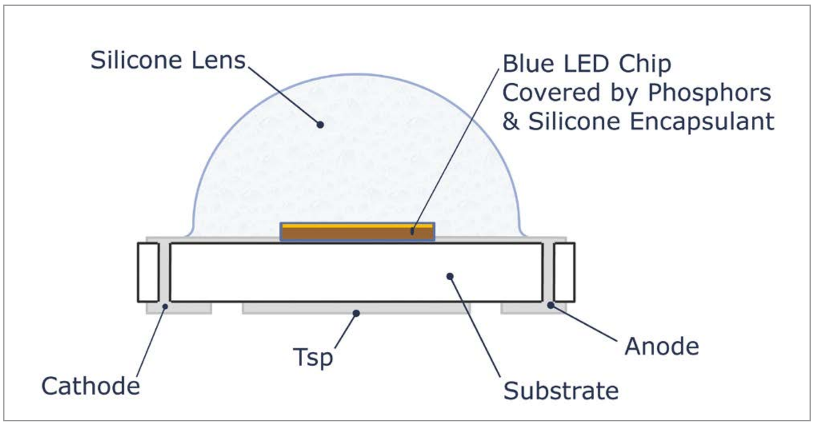



**Figure 1:** **Cross-sectional structure of a typical lighting-class LED**

The presence of volatile organic compounds (VOCs) in LED-based solid-state lighting (SSL) designs can impair the performance and reduce the lifetime of these illumination systems. Glues, conformal coatings, O-rings, gaskets and potting compounds are materials frequently used in the construction of LED based luminaires or lamps and often contain VOCs. The presence of chemically incompatible VOCs on or near LEDs can degrade the light output levels or cause changes in the chromaticity point of the light. Chemical incompatibility in SSL is often a localized phenomenon, occurring in luminaire designs that seal portions of the system, resulting in an LED's operating environment at elevated temperatures with little or no air movement. However, proper design and adequate testing can prevent chemical incompatibility effects. Most SSL luminiare types use a blue light LED chip covered with a yellow phosphor and encapsulant for converting the blue light to a broader white light spectrum. A silicone-based lens covers this whole LED assembly.

The unique silicone materials utilized in LEDs have excellent light transmittance characteristics: stable over wide temperature ranges, resistant to yellowing due to ultraviolet (UV) exposure and easily molded. This results in a high performance yet cost-effective LED. The basic structure of the LED's lens and encapsulants is a silicone polymer, which is a stable chemical compound.

Any VOCs present in a SSL system can diffuse into the gas permeable silicone lens and encapsulants of the LED. Within the molecular structure of these silicone materials, the VOCs will occupy a free space in the interwoven silicone polymer. With subsequent exposure to high photon energy emitted from the LED, along with the heat from the lighting system and the environment, the volatile compounds trapped in the LED's lens or encapsulants can discolor. This discoloration of the trapped VOCs can degrade the light emitted from the LED. This discoloration tends to occur in blue, royal blue and white light producing LEDs that use blue wavelength LED chips with yellow phosphors for spectrum conversion. This sensitivity to VOC is not unique to one LED manufacturer but is a known problem for all types of blue, royal blue and white light LEDs. Chemically induced discoloration is less prevalent and not as noticeable with amber, red or green LEDs since these color LEDs have longer wavelengths, therefore a lower frequency, and produce lower photonic energy compared to blue LEDs. Photonic energy (E) is defined by the Planck-Einstein equation of $E = hf$, where h is Planck's constant and f is frequency, thus a higher frequency produces a higher photonic energy.

## The Effects of Chemicals

Chemicals utilized in manufacturing SSL systems can result in LED light quality degradation or even complete luminaire failure. Figure 2 illustrates the degradation effect from a VOC on the silicone encapsulant that covers the LED chip.

The photograph on the left shows the normal appearance of an LED.
On the right, the same type XLamp chip has a pronounced brown discoloration due to exposure to VOCs while in operation with high photonic power output and at nominal environmental temperatures. This discoloration of the encapsulants is on the top of the LED chip, localized to the area just above the chip surface, closest to the source of heat and high photon energy. The VOCs occupying a free space within the lens or encapsulant typically do not cause permanent damage to the silicone material or the LED chip. In many instances, removing a secondary optic or otherwise venting the LED's environment will allow it to clear and recover in just a few hours of operation. However, the discolored VOC in the silicone polymer will not clear if the LED's operating environment remains saturated with the VOC.

Figure 3 shows graphic examples of this type of chemical degradation followed by out-gassing of the VOC, which clears up a darkened LED. In figure 3, photograph 1 is a VOC darkened LED caused by operation in an environment with incompatible VOCs. Photograph 2 is after 24 hours of operation in a VOC free environment and photograph 3 is after 48 hours without the presence of VOCs. Photograph 4 is after 72 hours of VOC-free operation and the LED is clear.

The application engineering team conducted a controlled chemical compatibility experiment to demonstrate and document the effect of this VOC reversibility on LEDs. Over an interval of 450 hours, three sets of 10 LEDs (30 LEDs in total) were first contaminated with a known high-VOC chemical and then for >450 hours tested for luminous flux output in three different test environments. One group was in an open-air environment, the second group in a sealed secondary optics environment and the third group started out with sealed optics, but later vented at 325 hours into the test.

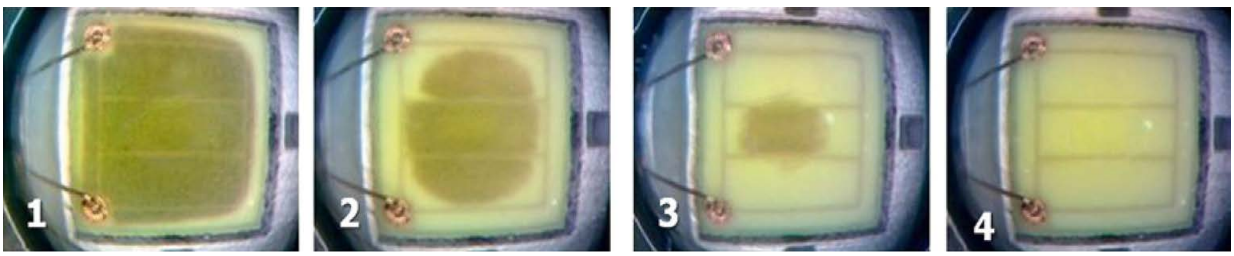
The first group of ten LEDs operated in the open-air environment and despite the deliberate contamination showed no degradation from the initial luminous flux measurements of approximately 100 lumens.
The sealed second group suffered a 90% loss of light output after 450 hours of operation. The third sample group of LEDs after 325 hours of operation also suffered a 90% loss of luminous flux output. Venting the enclosure of this third sample group allowed the VOCs to escape and 24 hours later, the third sample set of LEDs recovered virtually all of the lost luminous flux output. Figure 4 provides a graphical summary of the luminous flux output versus time for these three test cases.

## Chemical Compatibility Testing

Chemical compatibility testing validates that the chemicals or compounds within the SSL system are compatible with the LEDs utilized. The focus for this testing should be on gasket materials, adhesives, conformal coatings, soldering flux or any residual chemicals that may be in close contact to the LED lens and hermetically sealed with the LED.

**Figure 2:** **Examples of normal (left) and VOC degraded (right) LEDs**

**Figure 3:** **VOC degraded LEDs allowed to out-gas**



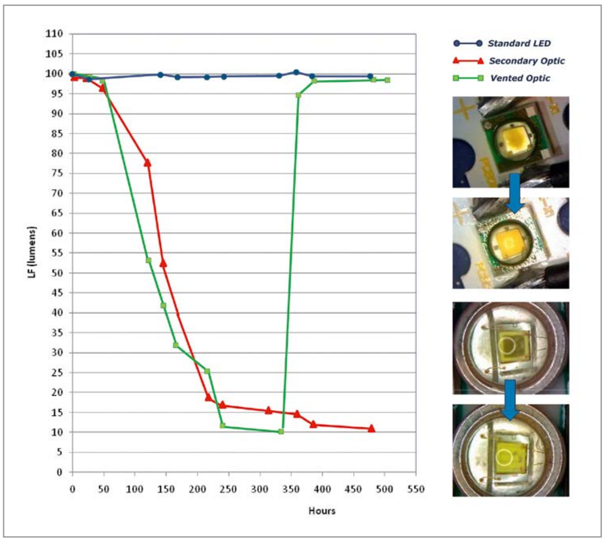



**Figure 4: Test results for VOC in vented and unvented designs demonstrate the reversibility of VOC discoloration in vented optics**

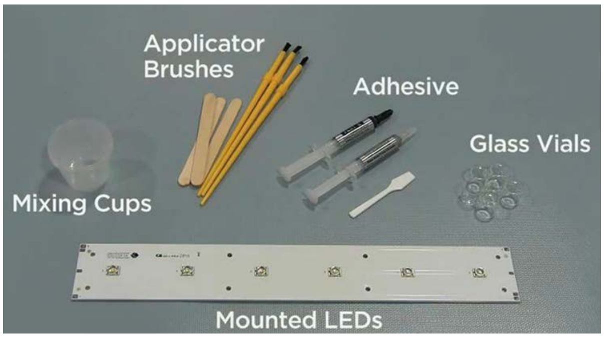



**Figure 5: Chemical compatibility test kits**

**Figure 6: Chemical compatibility test card in operation**

| Common Chemicals: |
|---|
| Methyl acetate or ethyl acetate (e.g., nail polish remover) |
| Cyanoacrylates (e.g., "Superglue") |
| Glycol ethers and dipropylene glycol monomethyl ether (e.g., electronics cleaners) |
| Formaldehyde or butadiene (e.g., PLIOBOND® adhesive) |
| Chlorine, including bleach cleaners and sprays |

**Table 1: Common chemicals with known LED compatibility issues**

| Conformal coatings: |
|---|
| Dow Corning® 1-2577 |
| Dow Corning® 1-4105 |
| Dow Corning® 3-1953 |
| Dymax® 9-20557 |
| Humiseal® 1B51NS |
| Humiseal® 1B73 |
| Humiseal® 1C49Lv |
| Humiseal® 1H20Ar1/S |
| Humiseal® Uv40 |
| Shat-r-Shield® |
| Specialty Coating Systems® – Parylene |
| Tech Spray® Turbo-Coat Acrylic Conformal Coating (2108-P) |
| This list is for informational purposes only and is no warranty or endorsement. The results obtained are specific to the test method, volume and material applied and environmental conditions under which it was performed. To verify compatibility, it is recommended that all chemicals and materials be tested in the specific application and environment for which they are intended to be used |

**Table 2: Conformal coating compatible with XLamp LED**

A chemical compatibility test kit for various LED product lines helps to identify critical VCOs. The kits are complete with a metal-core circuit board populated with six LEDs and glass vials with adhesive to create an airtight test environment. Figure 5 is a photograph of a chemical compatibility test kit for XR-E devices with all the supplied test materials.

The test kits utilize small sealed glass enclosures that test a single material or chemical sample for any effect on a single LED. The proper test setup is to place material under test on top of the first three LEDs on the board, then place the same test material at the base, away from the lens, of the next two LED components. The final LED will be the control reference and tests an LED without any sample material. An airtight seal, made with the Arctic Silver adhesive, around the diameter of the glass vials covers the LED and sample material.

Wires from a constant current supply connect to each chemical board. Drive current varies based on component type for these tests, 700 mA for the XP-E and XR-E LEDs and 350 mA for the MX-6 LEDs. Typically, testing is for about 1000 hours, monitoring for changes in light intensity or color or simply just visual appearance of the LED's phosphor layer with the LED turned off. Test results indicating chemical compatibility issues often show up in 48 hours after initial illumination. Figure 6 shows a typical chemical compatibility test setup under operation for about 720 hours and it is easy to note the color shift in the LED third from the left and a significant dimmer LED, which is fifth from the left.

## Summary of the Testing Results

Many common chemicals can outgas aromatic hydrocarbons, that are arenes, and fumes from even small amounts of these chemicals tend to discolor or damage the light output from LEDs. Table 1 contains a list of common chemicals that were found to be harmful to the tested LEDs, and therefore not recommended to be used in or around a LED based SSL system.

Table 2 offers a brief list of circuit board conformal coating materials that showed to be harmless when tested.* However, do not apply conformal coatings directly on to the LED lens, as this may affect the LED optical performance and reliability.

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**Table 3: Material compound compatibility list**

| Material Compound Tested | Type | OK in XLamp Designs* | Outgas Tested | Issues Found | Issues Suspected |
|---|---|---|---|---|---|
| Acetic acid | Acid | | | | Yes |
| Acrylic rubber | rubber/plastic seal | | | | Yes |
| Acetone | manufacturing material | | | Yes | |
| Acrylonitrile butadiene styrene (ABS) | Structural plastic | Yes | | | |
| Ammonia | Alkaline | | | | Yes |
| Benzene | Solvent | | | | Yes |
| Butadiene rubber | rubber/plastic seal | | | | Yes |
| Butyl rubber | rubber/plastic seal | | | | Yes |
| Chlorinated polyethylene | rubber/plastic seal | | | | Yes |
| Chlorobutyl | rubber/plastic seal | | | | Yes |
| Chlorosulphonated rubber | rubber/plastic seal | | | | Yes |
| Cyanoacrylate | Sealant and adhesive | | Yes | Yes | |
| DCA SCC3 | Coating/potting | Yes | Yes | | |
| Dichloromethane | Solvent | | | | Yes |
| epichlorhydrin | rubber/plastic seal | | | | Yes |
| Gasoline | Solvent | | | | Yes |
| Graphite gasket | Thermal compound | Yes | Yes | | |
| Halogenated hydrocarbons | | | Yes | | Yes |
| HT902 | Coating/potting | Yes | Yes | | |
| Hydrochloric acid | Acid | | | | Yes |
| Isopropyl alcohol (IPA) | Cleaning agent | Yes | Yes | | |
| meK (methyl ethyl ketone) | Solvent | | | | Yes |
| mIBK (methyl isobutyl ketone) | Solvent | | | | Yes |
| mineral spirits | Solvent | | | | Yes |
| Nitric acid | Acid Cleaner | | | | Yes |
| Non-silicon thermal grease | Thermal compound | Yes | Yes | | |
| Petroleum | oil/lubricant | | | | Yes |
| Polycarbonate (PC) | Structural plastic | Yes | | | |
| Polyethylene | rubber/plastic seal | Yes | | | |
| Polypropylene (PP) | Structural plastic | Yes | | | |
| Polystyrene (GPPS) | Structural plastic | Yes | | | |
| Potassium hydroxide | Alkaline | | | | Yes |
| Silicone oil | oil/lubricant | | | | Yes |
| Sodium hydroxide | Alkaline | | | | Yes |
| Sulfuric acid | Acid Cleaner | | | | Yes |
| Tetracholoromethane | Solvent | | | | Yes |
| Tetradecylamine | | | | | Yes |
| Thermal transfer grease (silicone based) | Thermal compound | Yes | Yes | | |
| Thermal transfer tape (with or without adhesives) | Thermal compound | Yes | Yes | | |
| Toluene | Solvent | | | | Yes |
| Trimethylhexamethylene diamine | | | | | Yes |
| Xylene | Solvent | | | | Yes |

Many of these chemicals and compounds are acceptable (OK) in XLamp LED-based luminaire and lamp designs. However, no chemicals or materials should be used that have been found or suspected to have an adverse effect on device performance or reliability. The results obtained and listed are specific to the test method, volume and material applied and environmental conditions under which it was performed. To verify compatibility, all chemicals and materials should be tested in the specific application and environment for which they are intended to be used. This list is provided for informational purposes only and is not a warranty or endorsement.

Compatibility test results obtained for common materials compounds are outlined in table 3. These test results are specific to the test method, volume of material applied and environmental conditions encountered during the testing. For new designs, all chemicals and materials utilized in a SSL product should be compatibility tested with the specific type of LED and under the environmental condition in which they will operate.

To help speed up the adoption of LED based SSL, some LED providers started programs to help lighting manufacturers find complementary components from third-party manufacturers that work with their LED products, like the Cree Solution Provider Program (CSP). The CSP helps lighting manufacturers with their LED lighting design requirements and can enable a shorter design cycle to get products to market faster. As part of this CSP activity, Henkel, a major manufacturer of materials for use in electronics, has helped to develop a chemical compatibility reference guide for LEDs. This guide, based on test results from the chemical compatibility test kits, covers thread-lockers, general bonding, potting compounds, lens bonding and sealing products that have been found to be compatible with LEDs during testing.

In conclusion, VOCs emitted from materials used in the construction of LED based SSL systems can penetrate the silicone lenses and encapsulants of LEDs. These VOCs in the silicone can discolor when exposed to heat and high photonic energy of the LED. The result can produce significant loss of light output or color shift from the LED. Proper material selection for the SSL design and venting of the enclosure or secondary lens assemblies reduces the risk of chemical compatibility issues in SSL luminaire systems. Compatibility testing of the materials selected for the assembly of the SSL system can help ensure the long-term high performance of lighting-class LED designs. ■

# Natural Design for Heat Sinks

The luminous flux of LEDs decreases with the rise of the operating temperature. Therefore the dissipation of the heat is, aside from the efficiency of the LED chip itself, an essential part in the development of efficient LED systems. Christian Herbold and Cornelius Neumann from the Light Technology Institute at the Karlsruhe Institute of Technology analyzed natural inspired shapes and show an approach to heat sinks that combine high thermal performance with a high aesthetic value.

The luminous flux of LEDs decreases with the rise of the operating temperature. Therefore the dissipation of the heat is, aside from the efficiency of the LED chip itself, an essential part in the development of efficient LED systems. The request for smaller LED luminaires with higher light output makes it more and more important to care about a potent heat management. Unfortunately powerful heat sinks are often in conflict with the desired product design of the luminaire. To avoid this, they are frequently covered or modified, which results in an advanced appearance but leads to a reduction of the thermal performance. Could it be possible to solve this problem with a look at nature?

The analysis of natural inspired shapes will show an approach to heat sinks that combine high thermal performance with high aesthetic value. Based on mathematical models and computational fluid dynamic analysis, a branched architecture was improved to obtain high performance heat dissipation. In addition, the resulting geometry shows a natural aesthetics that can serve as the origin for the design of efficient and beautiful luminaires. The modeled heat sinks are manufactured with metal injection molding to evaluate the process for the construction of such parts.

## Basic Problem

Most properties of an LED depend on the temperature. Not only the luminous flux and therefore the efficiency but also the lifetime, wavelength and the chromaticity coordinates change with temperature. The higher the temperature, the more the properties are influenced negatively. In general, there are three physical mechanisms to transport heat: radiation, conduction and convection.
The design of a heat sink has to consider these mechanisms to improve the thermal performance.

In comparison to traditional incandescent lamps the thermal power loss of the LED itself is not radiated and has to be dissipated by thermal conduction from the LED into the applied heat sink. The design of the heat sink has to ensure that the heat is conducted through the material to the surfaces where it is transported to the environment by convection and radiation.
Considering a given space available for a heat sink and thus the same surface area of circumference, the special design of the heat sink has a minor impact on the heat dissipation by radiation whereas the heat conduction and convection are effected by the material and the geometry of the heat sink.
Thus, the design of a heat sink has to fulfil two aims: good thermal conduction in the heat sink and good thermal convection on its surfaces.

## Basic Idea

A look at nature could possibly help to find architectures that support this solution. Evolution formed methods optimized for specific tasks that are efficient when it comes to the use of energy and material. This efficiency is advantageous to survival when there is limited availability of plant nutrients, space or light. The requirements of a living organism differ from the utility function in technology and therefore the approaches taken from nature cannot be copied for their technical use. Naturally inspired principles in technology must therefore be abstracted from their natural model to serve as innovative and powerful solutions.

When comparing the tasks of organisms absorbing and distributing energy in the form of nutrients with the task of the heat sink transporting and dissipating energy in the form of heat, the similarity is obvious. The results of the evolutionary process are efficient solutions for these tasks in many different structures. For example; the branched system of the human blood circulation or the venation of leaves. The architecture of tree branches or tree roots are both shaped efficiently in order to take in and transport plant nutrients while saving material and conserving the structural stability. Although the specific design varies even within the same species influenced by environmental effects, the basic principle of the branched architecture is always the same. For millions of years evolution formed these efficient shapes that everybody knows from every day life. This has always made nature a source of inspiration when it comes to the design of the human environment. Many successful designs were built on natural models with shapes and processes that build a harmonic balance with the environment [1]. Therefore heat sinks for LED systems could benefit in two ways from a natural inspired design. They may take advantage of a natural architecture in regards to the technical function of dissipating heat and, in addition, they connect the intrinsic beauty of nature with the design of the luminaire.

## Technical Investigation

Determining technical performance of branched heat sinks for LED systems is done in several steps. After applying a mathematical approximation to analyze the basic factors, CFD (computational fluid dynamics) simulations are performed to get detailed knowledge of the processes in the heat sink. In a final step a reference heat sink is produced to provide real world measurements and a comparison to the predictions of the simulation. To follow the constraints of most LED applications in general lighting, only the free air convection without supporting fans is examined. In addition all heat sinks considered are based on a round footprint. This shape supports the natural example, follows the circular spreading of heat from the source and orientates on the common design of luminaires that are mostly built rotation-symmetrically. With regard to the latest high power LEDs that offer more than 1,000 lm out of one package, the heat sink is designed for a system with a single LED of several Watts electrical power.

The characteristic number to describe the ability to dissipate heat in general is the thermal resistance Rth with the unit K/W that expresses the rise in temperature per thermal power put into the system. The better the heat is dissipated, the smaller the thermal resistance of the component is. A mathematical approach was used to estimate the thermal resistance of naturally branched structures. It is based to the assumption of the steady state and considers the energy loss in the branch by heat conduction and heat convection. The bifurcations are modeled by a recursive rule to calculate the thermal resistance of the whole branch. Input parameters are geometric properties of every single sector of the branch including its length, width and height, the thermal conductivity of the material and the heat transfer coefficient on the surfaces. This coefficient takes account of the geometry of the heat sink because it respects the flow conditions round the surfaces that are influenced by the space available for air flow. Details of this approach are described in [2].

The mathematical approximation is compared to more accurate but also more complex thermal simulations of the same branch. Based on numerical fluid mechanics, the simulations are performed for a high resolution mesh of discrete volumes of the branch model. To achieve precise results the small structures in the branches are considered by refining the mesh in the corresponding areas. The results compared to the approximated calculation are shown in figure 1 for a branch with different numbers of bifurcations but the same total length. Although there is a difference in the absolute values, the trend of both curves is similar. With an increasing number of bifurcations, thermal resistance initially decreases. After reaching its minimum value it increases again. This effect is caused by a change in convective heat dissipation with the length of the branched sectors. Considering a constant total length and material volume of the branch the surface for convection is increased with every new bifurcation. At the same time each new sector reduces the space between the neighbor branches and affects the airflow between the surfaces negatively. At a specific number of bifurcations the reduced airflow no longer compensates the benefit from the newly generated surfaces. In consequence the thermal resistance rises. If the spacing between the surfaces is too small, the fluid-flow through the channels is hindered and the heat transport by convection is reduced.

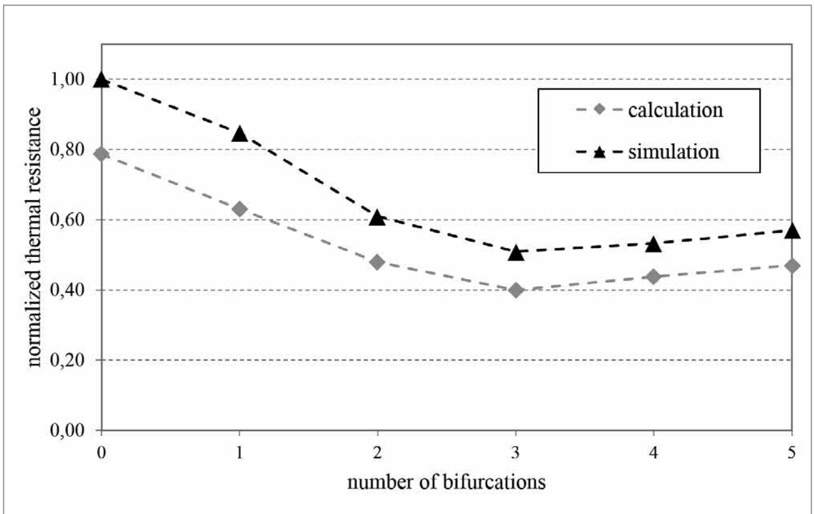


**Figure 1:** **Approximately calculated trend of thermal resistance for one branch (grey) and simulation results of the same branch (black)**

## Branched Design

Based on the results of the mathematical approximation, different parameters of the geometry are evaluated in detail by thermal simulations. The design of the simulated heat sinks is based on the branched architecture and meets the requirements of a small luminaire based on a single high power LED. The branches are constructed in one plane that is extended in the third dimension to form a cylindrical body. To ensure the comparability of the different designs, this cylinder has a diameter of 50 mm and a height of 50 mm in every design. All simulations are performed with a thermal power dissipation of 7 W on an area of 5 mm x 5 mm in the middle of the bottom end plane. This power dissipation corresponds to at least 10 W electrical power input at the LED.

 

**Figure 2:**
**Top view of heat sink simulation models with different number of branches**

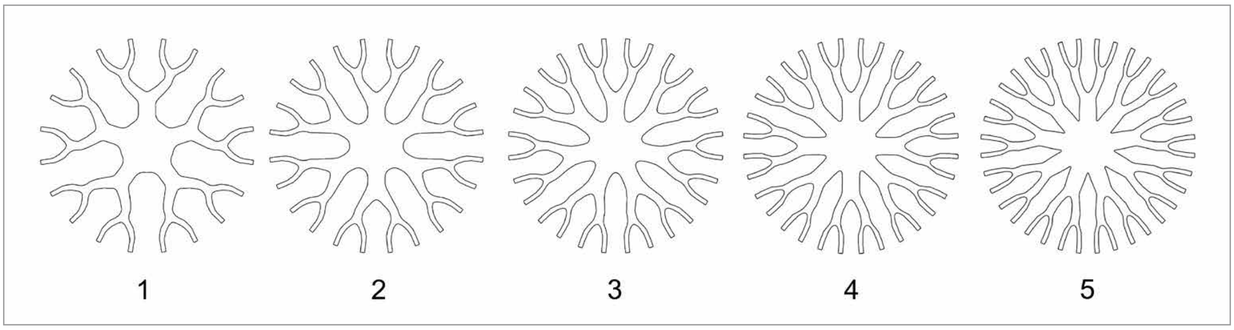


**Table 1:**
**Simulation results for different numbers of branches**

| Heat sink | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Number of branches | 5 | 6 | 7 | 8 | 9 |
| Normalized thermal resistance | 1.10 | 1.06 | 1.00 | 1.06 | 1.12 |

The heat sink design for the available space is determined on the basis of the mathematical model in conjunction with several thermal simulations and approximated with the numbers of branches, bifurcations and the bifurcation angle. The number of bifurcations corresponds to the value of three. The width of the branches is thereby specified not only to allow a sufficient thermal conduction but also for mechanical stability reasons and the ability of the manufacturing process. A minimum width of 1 mm complies with these requirements. With every bifurcation the width of the branch is divided in half. On the one hand this maintains the cross section constant for the thermal conduction, on the other hand it assures the stability needed during the production of the part. The minimum given thus defines the width of the previous sectors to 2 mm and 4 mm, respectively. All these specifications describe the major geometry of the heat sink but leave space for details that have to be examined. One example is the number of branches that directly influence the spacing between the surfaces. The heat sinks in figure 2 contain five to nine branches with two bifurcations in every branch. The simulation results in Table 1 show that the lowest thermal resistance of these designs is achieved with seven branches where the difference is up to 12%. The low number of branches in heat sinks 1 and 2 wastes space for additional surfaces while the large surfaces of heat sinks 4 and 5 cause narrow flow channels between the branches. This effect corresponds directly to the optimal spacing that is described for parallel plates in [3] and approximated for a more practical use in [4].

## Comparison

The performance of the branched heat sink is compared to the thermal resistance of a non-branched heat sink to validate the predictions of a lower thermal resistance with a branched architecture. The non-branched heat sink is designed to match the geometrical parameters of the branched heat sink. With the same constructed size (diameter and height) and the same diameter of the core, the material volume and the surface area differ with less than 1%. This leads to a conventional design with 17 fins. The difference between branched and non-branched design is expected to rise with the diameter of the heat sink because of the higher difference in spacing for larger diameters. Although the given diameter of 50 mm is relatively small to demonstrate the advantages of the branched design, the results of the thermal simulations confirm the expectations. Figure 3 shows the temperature distribution on the surface of both types as well as the flow velocity in the center plane. The higher temperatures and the areas with low flow velocity at the branched heat sink are obvious. The thermal resistance of the non-branched heat sink is 8.3% higher compared to the thermal resistance resulting for the branched version. With the manufacturing of both heat sinks it will be evaluated if this advantage can be transferred in a real heat sink.

## Manufacturing of Prototypes

The heat sinks are manufactured as samples considering a large scale manufacturing process. The injection molding offers the combination of high quantity parts with a high level of design freedom. The typical application for injection molding is the production of plastics parts. However, with the option of powder injection molding the same process can be extended to metals and ceramics from which copper was chosen for the first sample parts due to its high thermal conductivity compared to other metals.

For the injection molding process copper powder is mixed with a polymer as binder and granulated to compose the feedstock. The feedstock is melted and molded on a conventional injection molding machine Arburg Allrounder 570 S. The resulting green part has the final shape but not the final size because it still consists of copper powder and the binder material. The water soluble part of the binder can be removed of the part in a water bath. It still remains the so-called backbone that slightly connects the powder particles and keeps the part in its shape. A drying process follows because it is necessary that no water is present during the next step. This step consists of the thermal de-binding to remove the backbone and the sintering to produce a dense part out of the powder.

Metal injection molding (MIM) is mostly used for small parts with typical weights between 1 g and 100 g [5].

 

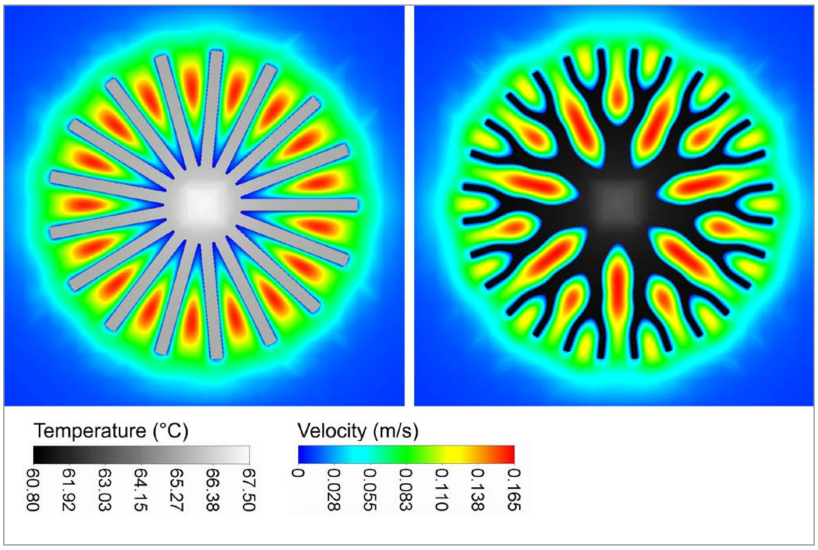


**Figure 3:**
**CFD simulation results for temperature and flow velocity for branched and non-branched heat-sinks**

Parts like the constructed heat sinks with about 330 g raise two problems for the injection molding of metals. The size makes it difficult to fill the whole cavity with melt before it solidifies. Once filled, the large surface causing a large surface adhesion prevents an easy ejection of the molded part. The cylindrical shape of the sample heat sinks offers two advantages to deal with these problems. Due to the extruded geometry the whole cross-section area can be used as ejector. For this reason, the pressure to push the molded part out of the cavity is applied to the complete cross-section area and the risk of destroying the part during ejection is reduced.

Furthermore, with this construction the ejector can be used for compression molding to support the filling of the cavity. During the injection the volume of the cavity is enlarged with back-pressure against the injected melt. Thereby the melt completely fills the available volume. These two additional functions of the ejector support the manufacturing of reasonable parts but small defects still remain on the final samples. It is not possible to eject a completely filled heat sink with high contour accuracy without destroying it. Due to the surface adhesion the fins break on the bond to the core of the heat sink. By slightly reducing the filling degree the parts can be ejected without breaks but the molded heat sinks have some notches on the fins where the cavity was not completely filled.

The following de-binding and sintering process finish the parts. During the sintering the heat sinks shrink evenly to about 85% of the size of the green part. A shape distortion caused by the shrinkage can almost be avoided with an appropriate sintering support that minimizes friction between the parts and the base. Figure 4 shows the sintered heat sinks of both types. The shapes represent the constructed geometries very well. The notches caused by the necessary reduced filling degree can be seen at half height of the parts. The difference in weight is slightly higher than expected. The branched heat sink is 6% lighter than the non-branched type.

**Figure 4:**
**Metal injection molded copper heat sinks after sintering**

## First Measurements

For the thermal analysis of the heat sinks the thermal transient testing method is used because of its accuracy and the ability to characterize the heat sinks in the system they are designed for.
When measuring the thermal behavior of LED systems a combined thermal and radiometric measurement setup has to be used since the supplied energy is dissipated in the form of light and heat. To avoid the need for a combined measurement and the related uncertainties, a diode is applied to the heat sinks. This diode features the thermal dissipation of all electrical power that is brought into the system with a similar footprint to the LED. First measurements support the predication from the simulations although the measurements have not yet been performed with the power the heat sinks were constructed for. Therefore the difference of 5.2% between both designs is lower but observable. In the next step the heat sinks will be characterized for full heat dissipation. Optical measurements with LEDs will supplement the results and a comparison to standard heat sinks will be possible.

**Figure 5:** **Possible heat sink design based on branched architecture**

## Conclusions and Outlook

Inspired by natural architecture, branched structures were analyzed concerning their ability to serve as heat sinks in LED applications. Based on an approximate mathematical model and several thermal simulations a branched heat sink was designed. A corresponding heat sink in a conventional non-branched design serves as reference. The comparison to thermal simulations results in an advantage of 8.4% for the branched heat sink in the given size. Both designs were manufactured from copper with metal injection molding. First measurements confirm a slightly lower thermal resistance of the branched heat sink. Although the advantage in performance is small in these models, the advantage in the design is still evident (Figure 4) even if the design freedom given by the manufacturing process of MIM is not extensively used. Compared to a luminaire with covered heat sink, an increased difference in performance will be obvious. Therefore an additional design will be manufactured to combine the natural shapes with the possibilities of the process. Heat sinks with larger diameters will extend the advance in thermal resistance.
The beauty of the branched architecture is certainly worth thinking about luminaires designed on this principle, joining aesthetics and performance (Figure 5).

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# The Necessity and Feasibility of Production Testing for LED Lighting Products

LEDs are widely recognized to be the next dominant lighting technology. But to provide consistent quality, efficiency and light parameters, performance tests in production lines are desirable. These tests are difficult to perform automated in production lines, especially for larger DUTs, such as LED tubes. Bernie Chang, manager at Chroma ATE's product marketing department presents an innovative test method that is capable to measure key performance parameters.

LED lighting is well known as an energy saving and eco-friendly light source technology, and it is widely believed that these features will eventually make the LED the dominant technology in the lighting market. However, today's relatively much higher LED lighting products prices obstruct market adoption. Besides the price issue, in the early development stage and marketing, the inconsistent specification claims, uncertain performance quality, and unpredictable reliability were also concerns of the consumers. Several standards have been published to provide the baseline to evaluate LED lighting performance. However, these standard measurement methods only focus on measurement accuracy; other things like test speed, tool sizes, and convenience of loading/ unloading are not taken into consideration. Thus, the standard measurement methods tend to be restricted to the laboratory, and therefore, one may easily raise a question: can product quality be assured if only limited samples are tested in a laboratory? Is there an alternative method designed for production testing?

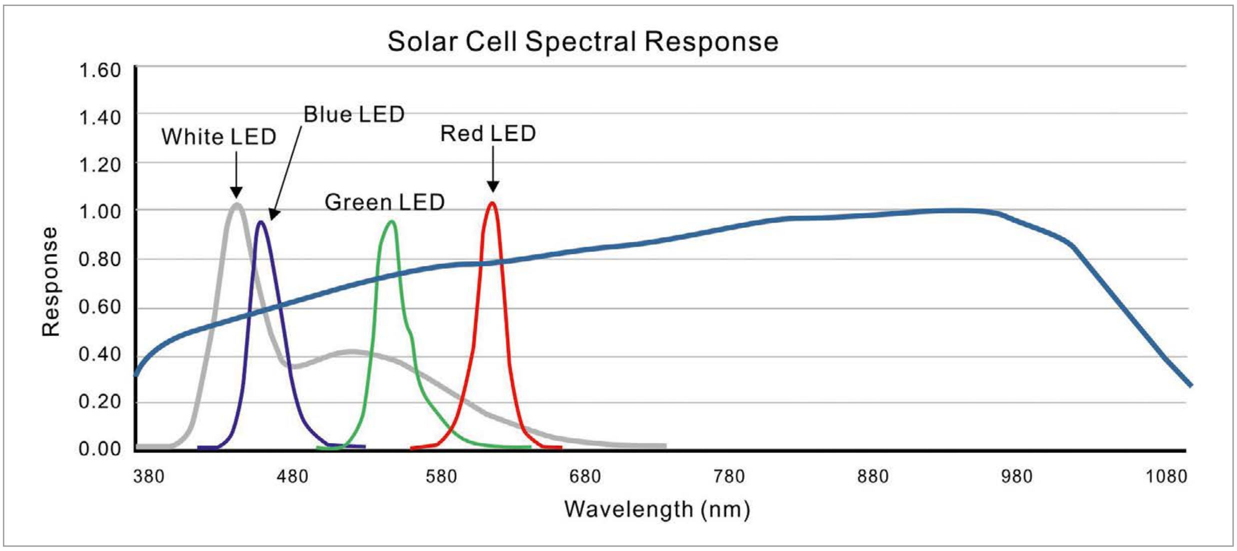
A newly elaborated test method is capable of measuring total luminous flux, CRI, CCT, flicker, and spatial distribution to name just a few. Several experiments have been done, showing the measured value correlating to integrating sphere's value well. Real production test data from a LED lighting manufacturer is provided, and the latest U.S CALiPER summary report is discussed; both of them implied the necessity of a production test. The implementation of this method features in compact size, high test speed, and high cost effectiveness, which all make it easy to combine with an automatic machine so that a 100% production test is feasible.

## Standard Laboratory's Measurement Method

There are several standards regarding LED lighting products. Among these standards, Illuminating Engineering Society's (IES) LM-79[1] is the most widely used for electrical and photometrical measurement. LM-79 describes the IES approved methods of the standard procedures for electrical and photometrical parameters measurement, such as total luminous flux, electrical power, luminous intensity distribution, and chromaticity of solid-state lighting products for illumination purposes. For the optical parameters measurement, two methods are introduced: goniometer method and the integrating sphere method. As the standard methods, the measurement accuracy and reproducibility are the main focus; other things like test speed, tool sizes, and convenience of loading/ unloading are not taken into consideration. For example, it easily costs minutes to hours for a single DUT (device under test) measurement if using the spatially scanned goniometer method, depending on the scan resolution. The tool size of both methods is also not easy to be ignored. For example, to measure a 4 foot LED tube, the integrating sphere must be larger than 2 meters in diameter. The loading/ unloading of the DUT to goniometer or integrating sphere is also noticeably inconvenient. Therefore, although the standard methods may provide a very accurate measurement value, they are more suitable for laboratory use and are not practical to apply in the production line. With a limited number of sample tests in the laboratory, the quality of LED lighting products remains questionable.

**Figure 1:** **Mono-crystalline silicon solar cell spectral response**




## Innovative Production Test Method

Considerations for production testing may be different from standard testing methods. While accuracy and reproducibility are the only concerns for the standard test method, the footprint of the tool, the test speed, the convenience of operation, and the test cost are also important factors in production testing. The main purpose of the production test is to assure consistent product quality. The measurement accuracy is important, but more tolerable than the standard method. If a test system may satisfy criteria like compact tool size, high test speed and high cost effectiveness, and the measured value correlates to the laboratory's standard measured value, the test system is suitable for production testing.

An idea to meet these criteria is to appropriately arrange photo detectors around the DUT so that the size of the test system can be larger than the DUT. The compact size of the tool makes it easier to operate and also makes it easier to combine with an automatic machine. However, to get adequate optical power from the DUT, the number of photo detectors must be very large which increases the cost. If there is a low cost big-area detector available, the number of photo detectors can be reduced significantly and the cost effectiveness target met.

### Theory

If using mono-crystalline silicon solar cells as photo detectors, the big area of solar cells may reduce the number of detectors while still maintaining adequate coverage, and the price of commercially available solar cells is also competitive. The typical spectral response of a commercially available mono-crystalline silicon solar cell is shown in Figure 1. It's not hard to find it has very good spectral response to the spectrum range for all visible LEDs known today. Also, the Isc, short circuit current of the solar cell is a function of the radiation which is the total radiant power received over the active surface of the solar cell. Therefore, by measuring the short circuit current with known absolute spectral response of the solar cell and spectral luminous intensity distribution of the test LED, the total radiant power can be calculated mathematically.

The short circuit current of a mono-crystalline silicon solar cell with LED light shining on it, in theory, can be expressed as below:

$$Isc_{\_SolarCell} = \int_{\lambda 1}^{\lambda 2}\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} I_{\_LED}(\lambda,\theta,\phi)\cdot SR_{\_SolarCell}(\lambda,\theta,\phi)\cdot\sin(\theta)\,d\lambda\, d\theta\, d\phi \quad (1)$$

Where

| | |
|---|---|
| $\lambda_1$-$\lambda_2$ | is the spectral distribution range of the test LED |
| $Isc_{\_SolarCell}$ | is the short circuit current of solar cell |
| $I_{\_LED}(\lambda,\theta,\psi)$ | is the relative spatial radiant intensity of the test LED per wavelength |
| $SR_{\_SolarCell}(\lambda,\theta,\psi)$ | is the absolute spectral response of solar cell |

If assuming the relative spectral distribution of the test LED light shine on the solar cell is spatially uniform, and the absolute spectral response of the solar cell among active surface is also spatially uniform, equation (1) can be expressed as

$$Isc_{\_SolarCell} = k_1\int_{\lambda 1}^{\lambda 2}\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} Ir_{1\_LED}(\lambda)\cdot Ir_{2\_LED}(\theta,\phi)\cdot SR_{\_SolarCell}(\lambda)\cdot\sin(\theta)\,d\lambda\, d\theta\, d\phi \quad (2)$$

Through some mathematical derivations, the radiant power of the test LED light shine on one solar cell can be expressed as

$$P_{\_LED} = k \frac{Isc_{\_SolarCell}}{\int_{\lambda 1}^{\lambda 2} Ir_{1\_LED}(\lambda) SR_{\_SolarCell}(\lambda) d\lambda} \int_{\lambda 1}^{\lambda 2} Ir_{1\_LED}(\lambda) d\lambda \qquad (3)$$

And the luminous flux of the test LED can be expressed as

$$Lm_{\_LED} = k \frac{Isc_{\_SolarCell}}{\int_{\lambda 1}^{\lambda 2} Ir_{1\_LED}(\lambda) SR_{\_SolarCell}(\lambda) d\lambda} \int_{\lambda 1}^{\lambda 2} V(\lambda) \cdot Ir_{1\_LED}(\lambda) d\lambda \qquad (4)$$

Where V(λ) denotes luminosity function.

The implementation of the test system (hereafter referred to as PV module or solar cell box) is to appropriately arrange solar cells around the DUT. The arrangement is made according to the LED lamp form factor, for example, for light bulb form factor, the implementation is a square box; for LED tube, the implementation is a hexagon box (Figure 2, Figure 3).

The total luminous flux of the implementations is to sum up the luminous flux received by each solar cell (refer to equation (4)), and can be expressed as

$$total\_Lm = K \sum_{i=1}^{n} Lm_i$$

Where

| | |
|---|---|
| Total_Lm: | is LED lamp total luminous flux (lm) |
| Lmi | is luminous flux received by each solar cell |
| K | is a correlation factor of total flux and partial flux |

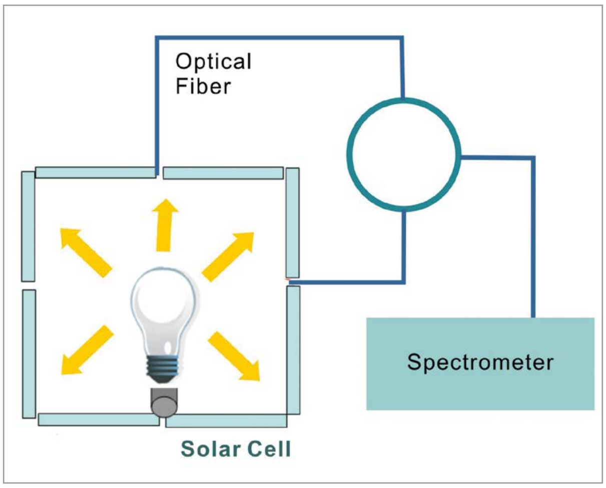



**Figure 2:** **PV module implementation for LED bulb**

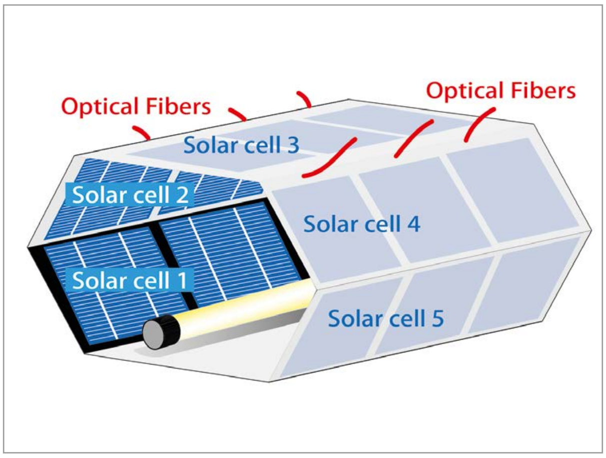



**Figure 3:** **PV module implementation for LED tube**

### System setup

According to Energy Star program requirement for integral LED lamps [2], LED lamps manufacturers have to offer electrical and optical parameters such as lumen, efficacy, power factor, correlated color temperature (CCT), color rendering index (CRI) to consumers.
The purpose of the system is to test all of these parameters in the production line, so that the quality consistency of the LED lamps can be assured.
The system is equipped correspondingly to have the capability of measuring total the luminous flux, chromaticity, and electrical parameters of the LED lamp.

The system includes an AC source, a power meter, a DC source, and optical measurement unit. Take the system for bulbs as an example; the system is as Figure 4 shows. The optical measurement unit includes a PV module and a spectrometer with multi-optical fibers. The so-called PV module is a square box and solar cells are placed on the inner surface planes. There are four pieces of solar cells placed on each surface of the square box. For chromaticity measurement consideration, a spectrometer is used and multi-optical fibers are inserted between solar cells as shown in Figure 2.
For other LED lamp form factors, like LED tubes, the system setup is similar, but the PV module is changed according to the form factor, like Figure 3 shows for the LED tube form factor.

**Figure 4:** Test system architecture for LED bulbs

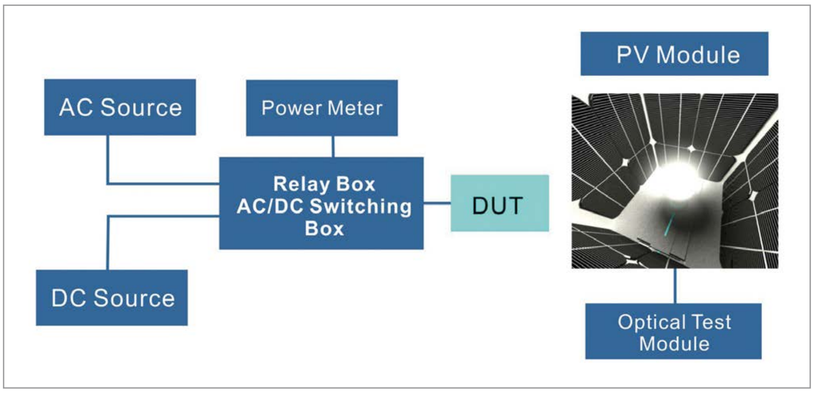



**Figure 5:** Repeatability histogram chart for luminous flux

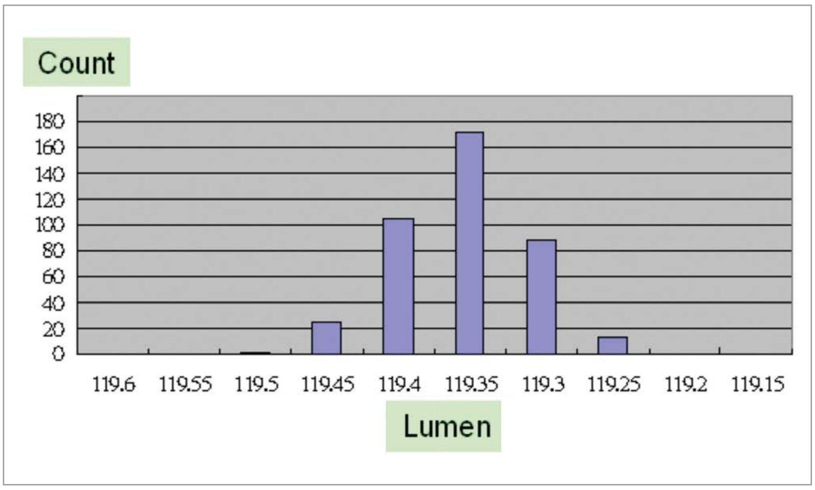



**Table 1:** System repeatability 400 times test result:
- **Luminous flux: (Max-Min)/Avg = 0.19%**
- **Max. Δu'v' = 0.00021**

| | Lumen | CCT | CRI | du' | dv' |
|---|---|---|---|---|---|
| Max. | 119.5 | 2664 | 98.6 | 0.00019 | 0.00017 |
| Min. | 119.2 | 2659 | 98.4 | -0.00019 | -0.00018 |
| Average | 119.3 | 2661 | 98.498 | 0.00000 | 0.00000 |

**Table 2:** Accuracy experiment summary

Type I: 7W warm white A19 LED lamp

| | Lumen | CIEx | CIEy | CCT |
|---|---|---|---|---|
| Max. error | 0.95% | 0.0023 | 0.0019 | 23.22 |
| Min. error | -1.92% | -0.0030 | -0.0016 | -10.08 |
| Avg. error | 0.01% | 0.0000 | 0.0000 | 0.00 |
| Std. | 0.85% | 0.0015 | 0.0010 | 10.61 |

Type II : 10W cold white A19 LED lamp

| | Lumen | CIEx | CIEy | CCT |
|---|---|---|---|---|
| Max. error | 0.75% | 0.0015 | 0.0011 | 28.37 |
| Min. error | -0.87% | -0.0011 | -0.0007 | -31.44 |
| Avg. error | 0.00% | 0.0000 | 0.0000 | 0.00 |
| Std. | 0.45% | 0.0008 | 0.0006 | 19.72 |

## Test Performance

The test performance of the system was evaluated by measurement repeatability and accuracy. The experiment results show that both the lumen and chromaticity repeatability are good, and the measured values are highly correlated to the values gotten from the integrating sphere. Both repeatability and accuracy experiments indicate that the test system is capable of performing production tests.

### System repeatability

In order to test the system repeatability, a stable light source is required. A halogen lamp was used as the DUT and it was seasoned for one hour. After one hour burn-in, the halogen lamp was installed into the PV module and measurement was performed 400 times. Refer to figure 5 and table 1 for the experiment results.

From Table 1, the luminous flux repeatability of the system is 0.19% and chromaticity CIEu'v' repeatability is 0.00021.

### Accuracy experiment

The accuracy evaluation experiment was to measure LED lamps value from PV module and laboratory standard integrating sphere respectively, and to compare the measured value. The benchmark integrating sphere system was a 50 cm integrating sphere with spectroradiometer. Two types of A19 LED lamps were tested and ten lamps for each type: type one was 7 W warm white lamp and type two was 10 W cold white lamp. All the lamps were burned-in for two hours before measurement, and all of the measured values were recorded after the readings of the luminous flux stable consecutively for 3 minutes, to assure the test was performed in steady state.

The experiment results are shown in figure 6 and figure 7. From the experiment summary table (Table 2), the measured values from PV module were well correlated to integrating spheres. The lumen value variation between PV module and integrating sphere is within ±2%, and less than ± 30 for CCT.

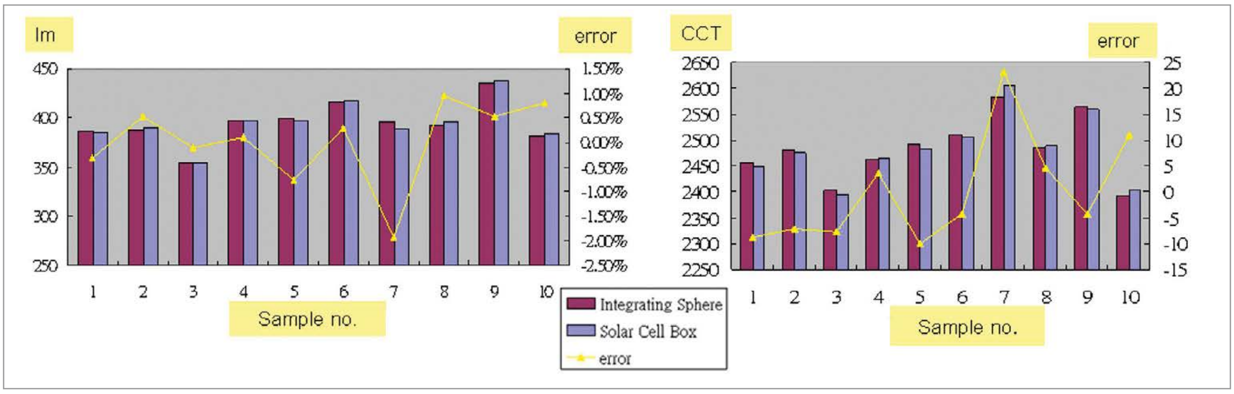



**Figure 6:** Measurement comparison from two systems (7W, warm white)

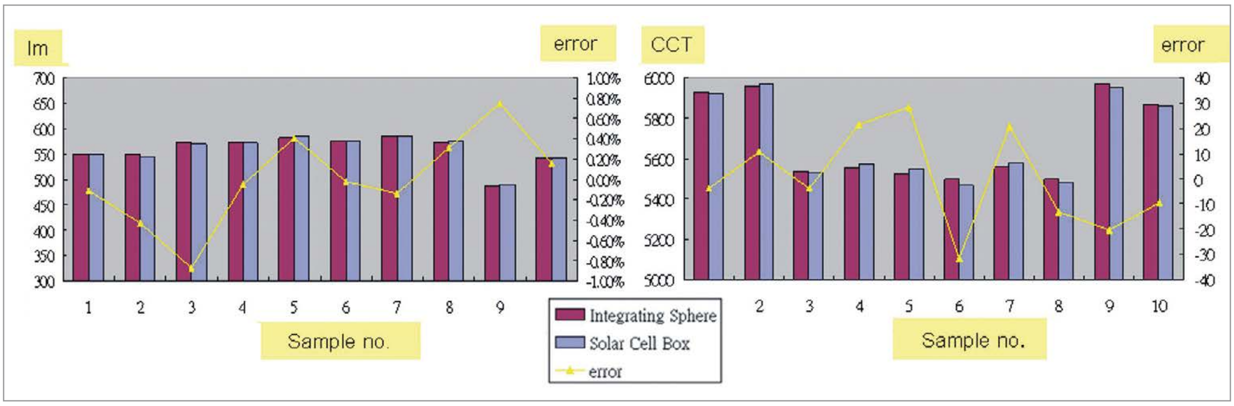



**Figure 7:** Measurement comparison from two systems (10W, cold white)

To summarize these experiments, the repeatability of the PV module method was good (lumen < ± 0.1%, max. Δu'v' = 0.00021). The measured values from PV module were well correlated to integrating sphere (lumen < ± 2%, CCT < ± 30). These values indicate the PV module system is capable for production test.

## Other Measurement Considerations

Besides the electrical-optical parametric test, there are other considerations that need to be cared for specifically for LED lighting product measurement. Three of them are discussed in this section: cold test / hot test, flicker measurement, and optical spatial distribution.

### Cold test / hot test

In the above experiments, to get stable LED light output, a proper pre-burn process was required. The LED light output is sensitive to temperature, or more precisely, the junction temperature of the LED chip. After turning on the LED lamp, the temperature generally goes up as time elapses, so the output light decays with time. If the test is performed right after the LED lamp is turned on, it is called a cold test, since the LED chip junction is still cold. If the test is performed when the light output is stable, it is called a hot test. Although the hot test value generally may correlate with the cold test value, the percentage of light decay is not the same for each lamp, because of the variation in material and production process (Figure 8). Because of the decay, only the hot test can reflect the real performance of the product.

In the LED lighting production process, manufacturers usually perform the burn-in process in a big burn-in room. Some may argue the pre-burn just before the test process is redundant. It that is true the test can be performed right after the burn-in process. However, practically the test is usually performed hours after this burn-in process and the LED lamps have already cooled down. The purpose of the burn-in process is usually because of concerns for reliability while the pre-burn before the test is for thermal equilibrium. Experiments show that even by only a minute turn-off before the test, the light output goes up compared with the steady state value.

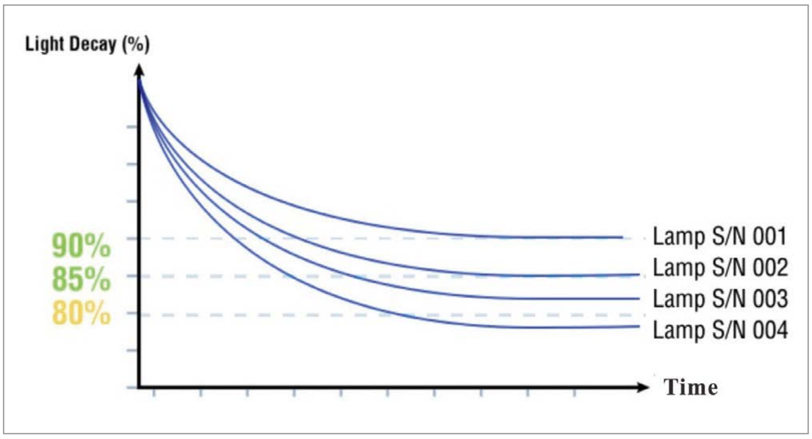



**Figure 8:** Light decay after the LED lamp is turned on. Different lamps may have different decay behaviors, because of the variation in material and production processes

### Flicker measurement

Flicker is also a concern for LED lighting. For other traditional lighting technologies, the flicker phenomenon is almost the same if using the same technology. However, in LED lighting, flicker may be very different from product to product, and make flicker measurement important to LED lighting. The major reason behind this is the different driver design.

ANSI/IES has defined two indices: Percent Flicker and Flicker Index for flicker [3]. Percent Flicker is based on light output amplitude variation and Flicker Index is based on the variation of the light output energy. Apart from them, the frequency of flicker is also important. Studies show that human eyes may perceive lower frequencies, but there is still some biological impact from invisible flicker [4]. Generally, current regulations require that flicker frequency, if any, must be higher than two times of the power line frequency, i.e. higher than second harmonic.

The response time of a mono-crystalline solar cell is fast, so that the PV module may sample the LED output optical waveform properly. Percent Flicker, Flicker Index, and frequency of flicker are calculated accordingly. In addition, the optical waveform is plotted with the voltage and current waveform to provide more useful information. Examples of these waveforms from two different LED lamp designs are illustrated in Figure 9.

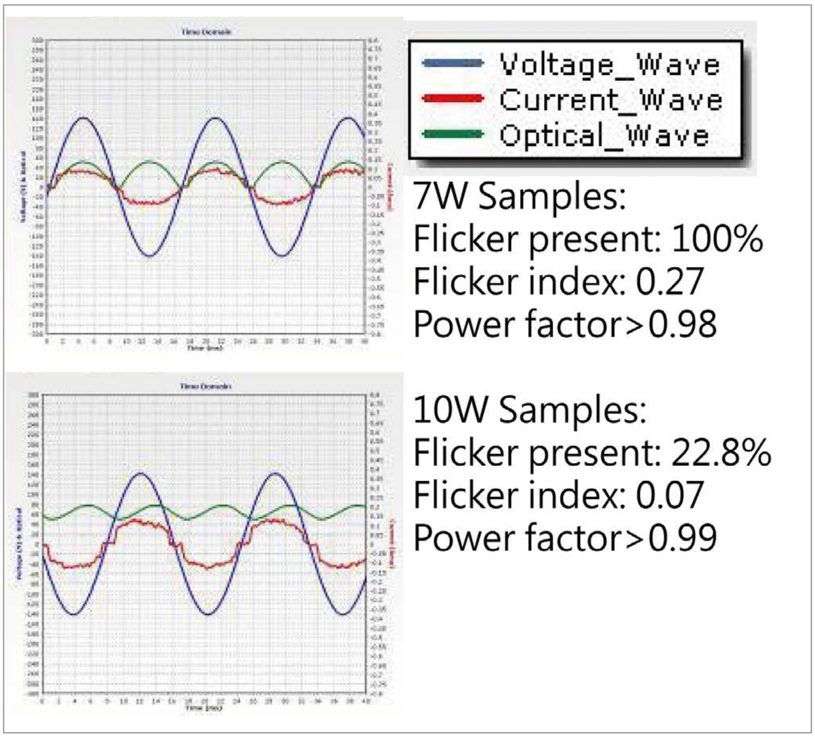



**Figure 9: Voltage, current, and optical waveform in time domain for different LED lamp designs**

### Optical spatial distribution

As a relative new technology of light source used in general lighting, the optical spatial distribution of the LED lamp is also a concern. Generally speaking, LED is a relatively more directional light source, and the beam profile of the LED chip may vary from one chip design to another. At the early stage of LED lighting development, most of the product designs needed a large heat sink, and the beam angle was limited, even for non-directional purposes. While replacing the incandescent lamp with this kind of design, consumers certainly cannot be satisfied. Nowadays, omnidirectional lamp designs are preferred, and some standards or government programs have a beam angle requirement. For example, the U.S Energy Star Program requests the luminous flux between 135° - 185° must be higher than 5% of the total luminous flux for omnidirectional lamps [2]. Another example is Japan JEL 801 also requests at least 30% of the luminous flux must emit beyond 120° for LED tube [5].

The arrangement of the solar cells in the PV module is designed to meet the above spatial test requirements. The solar cell on the bottom surface of bulb PV module (Figure 10) approximately represents the 135° - 185° zone for Energy Star Program request. Similarly, the top three solar cells in Figure 11 may also represent the 120° zone of LED tube for the JEL 801 requirement.

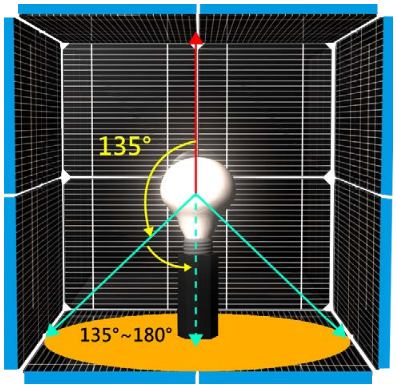



**Figure 10: PV module for optical spatial distribution measurement (for bulb form factor). The light received by the bottom surface may approximately represent the light output from 135° - 185° zone of the lamp**

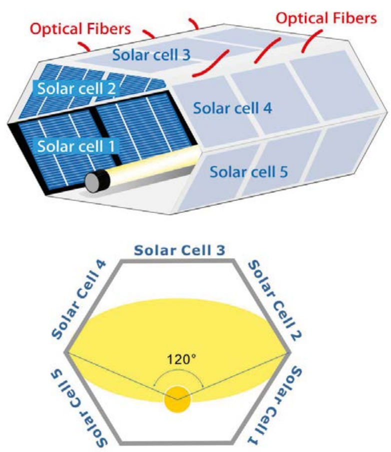



**Figure 11: PV module for optical spatial distribution measurement (for tube form factor). The light received by the top three surfaces may approximately represent the 120° zone of the tube**

## Combined with an Automatic Machine

The PV module test method is featured in compact tool size, high test speed, high cost effectiveness, and it is also easier to combine with an automatic machine. An example of how to implement the test method in a LED bulb fully automatic production line is shown in Figure 12 . The system is


**Figure 12:** **Automatic production test line with pre-burn module**

equipped with a pre-burn module in order to test in thermal equilibrium state. The pre-burn time is DUT dependent; typically 40~50 minutes is enough to perform steady state test.

The automatic line is "tray-in/ try-out" design. After loading the carrier tray, the pick & place arm pick up the LED bulb at the pre-burn module. After pre-burn for the set time, the bulb is placed on the conveyor and transfered to the PV module for testing. The "off time" of the bulb from pre-burn module to conveyor is only a few seconds so that the steady state remains. After the test, the DUT is sorted to the pass / fail bin carrier tray, according to the test result.

Test items of the PV module include, but are not limited to, input power, power factor, total harmonic distortion, luminous flux, correlated color temperature, color rendering index, as well as optical spatial distribution and flicker measurement.

## The Necessity of a Production Test for LED Lighting Products

There are arguments about the necessity of production testing for LED lighting products among LED lighting manufacturers. Some argue that production testing is not required for LED lighting products because the LED chips are already tested. Some may think the consumers or end users may not notice the quality issue. Some are concerned with the costs if applying the inconvenient standard measurement method in the production line, especially when all of the manufacturers are under price pressure.

Are these arguments correct? Is the quality of LED lighting products really as good as these manufacturers claim?

Two aspects can be discussed to answer this question: to analyze the LED lighting product quality in the production line, and to analyze the LED lighting product quality from the market. Here we provide facts from these two aspects: real production test data from an LED lighting manufacturer, and a market test report from a U.S government program.

## Facts from real production test data

Real statistical production data from an LED tube manufacturer is provided in figure 13. The nominal specifications are:

- 100 lm
- CCT = 6000 K
- CRI = 70

A two-batch run data is provided, showing there's a shift between two runs. The data also shows the span of the performance distribution is wide, even in the same run. Although the pass/fail criteria of this manufacturer are not strict, the fail rate is still noticeable. If such a wide performance distribution and such a high fail rate occur in production line, the product quality definitely cannot be assured without 100% production test.

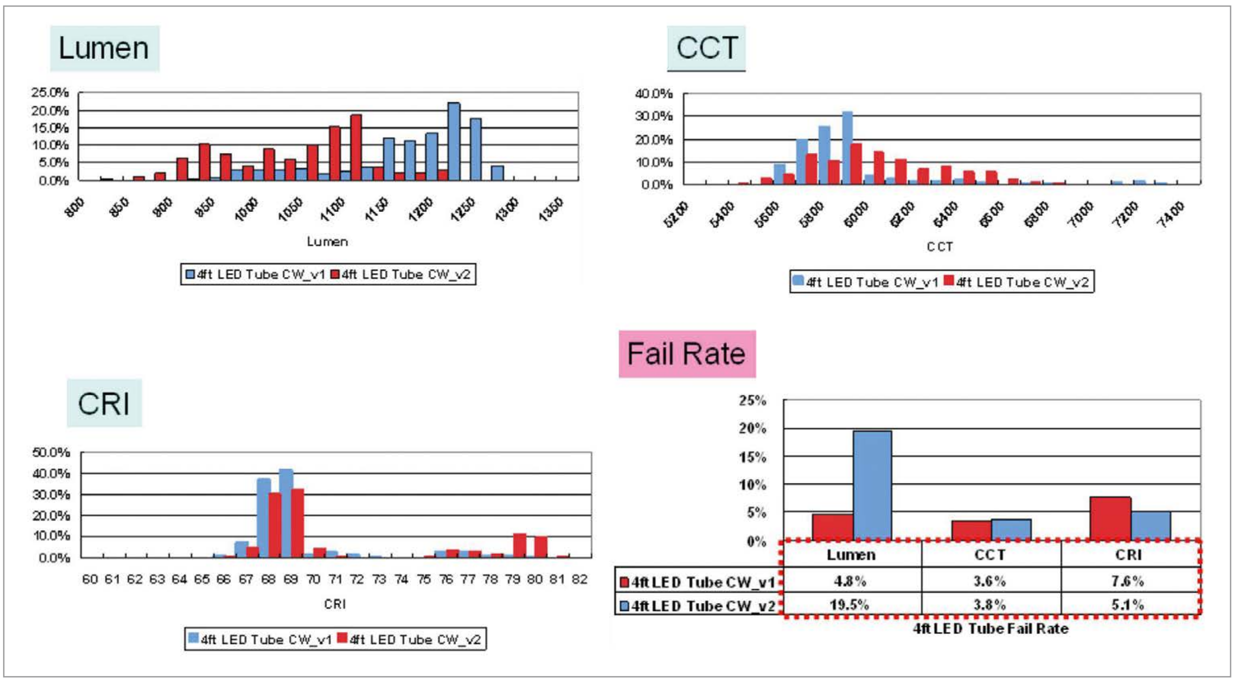



**Figure 13:** **Real production test data of a 4 foot LED tube from an LED lighting manufacturer**

## Facts from the U.S. CALiPER Program

The U.S. Department of Energy (DoE) CALiPER program is one of the U.S. DoE Solid State Lighting (SSL) programs. The program is to buy solid-state lighting products from the market, and perform the photometric testing based on LM-79's standard testing methods. The purpose of the CALiPER program is to provide the photometric data of the solid state lighting products which are available in the market, to have a glance of the technology trend, to provide a benchmarking baseline, and to check whether the performance is as good as the manufacturer's claim.

The CALiPER program has been purchasing and testing general illumination solid-state lighting (SSL) products since 2006. In the latest CALiPER Application Summary Report 20 [6], 38 LED PAR38 lamps (named as Series 20) were tested. Evaluating how close the real performance is to the manufacturers' claims is an important part of the CALiPER program. In this summary report, although most of the manufacturer claims for color related parameters were accurate, only 23 of these 38 samples met all three claims of input power, lumen output, and efficacy; as high as 40% of the samples failed to meet their claims for electrical / optical power related parameters.

LED Lighting Facts and Energy Star are also important programs of the U.S. government to build up consumers' awareness and confidence in LED lighting products. Among these 38 Series 20 LED PAR38 lamps, 21 of them were listed by LED Lighting Facts, and 18 of them were Energy Star qualified products. Although these products were tested and measured under standard procedures before being certified or qualified, the test result from the CALiPER program still showed a significant failure rate in meeting the manufacturers' claims (Table 3). The root cause of this phenomenon is unknown, however lamp-to-lamp variability is a possible factor suggested in the summary report.

**Table 3:** **Fail rate of Lighting Facts listed and Energy Star qualified products in CALiPER Application Summary Report 20**

| | Lighting Facts listed Total samples: 21 | | Energy Star qualified Total samples: 18 | |
|---|---|---|---|---|
| Items | Fail samples | Fail rate | Fail samples | Fail rate |
| Lumen output (lm) | 7 | 33.3% | 3 | 16.7% |
| Input power (w) | 5 | 23.8% | 1 | 5.6% |
| Efficacy (lm/W) | 6 | 28.6% | 4 | 22.2% |

From these facts from the CALiPER report, it implies that current sampling test in the production line is definitely not enough to make the products quality consistent. If there is no 100% production test there is more than a 40% chance that the products may fail to meet one or more of the claimed specifications.

## Conclusion

The accuracy and repeatability performance of the PV module test method are proven, and the test method is also proven to fit production testing requirements. If you combine this test method with an automatic machine and pre-burn module, 100% of steady state production testing can be easily done. Evidence from manufacturers and the U.S. government program all indicate the quality of current LED lighting products is not consistent, which certainly lower consumers' confidence in LED lighting. With a 100% production test, the quality can be assured, and LED lighting market adoption can be accelerated. ■

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[1] IESNA LM-79-08. Electrical and Photometric Measurements of Solid-State Lighting Products
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[6] CALiPER Application Summary Report 20: LED PAR38 Lamps


»To err is colour, light is the truth,« as the German lyric poet Emanuel Geibel wrote. But, apart from poetry, we all know that light decides how authentically colours can act on us. And it is precisely LED technology, with its new spectral properties and its option for dynamic light, that gives rise to new questions on the interaction between light-source spectra and the perceived characteristics of illuminated objects. This technical book provides fundamental knowledge and the latest scientific findings on the property of colour rendition fidelity.

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**Technology: "HD-Retina" LED Technology - Light Quality Beyond CRI**
A common assumption is that full sunlight offers ideal visual comfort. This is not the case, however, because full sunlight also tends to distort color. As an alternative, natural light that corresponds to between 3,500 K and 3,700 K has been identified to be ideal for human perception. The "HD-Retina" concept takes this finding into account. This article discloses the latest insights into color perception, how the new approach works and how it differs from other HQ high CRI systems.

**Manufacturing & Testing: Manufacturing Silicone Lenses and the Effect it has on LED Package Quality**
Silicone based materials offer performance and reliability advantages in LED lighting applications but they need special knowledge and manufacturing skills. The author explains the silicone optic lens injection molding process, specifications and properties of silicone injection lens molding machines, equipment and tools, the effects on package quality and reliability and durability tests.

**Thermal Management: Intelligent Over Temperature Protection for LED Lighting Applications**
LEDs offer an enormous amount of potential for saving energy and enhancing the quality of lighting. But lifetime and general LED performance are a function of junction temperature. System manufacturers are addressing this challenge by selecting improved thermal designs. Intelligent over-temperature protection by the LED driver IC can increase the lifetime of LEDs significantly, ensure performance over lifetime and reduce the number of defects.

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