



Research: Luminescent Glasses

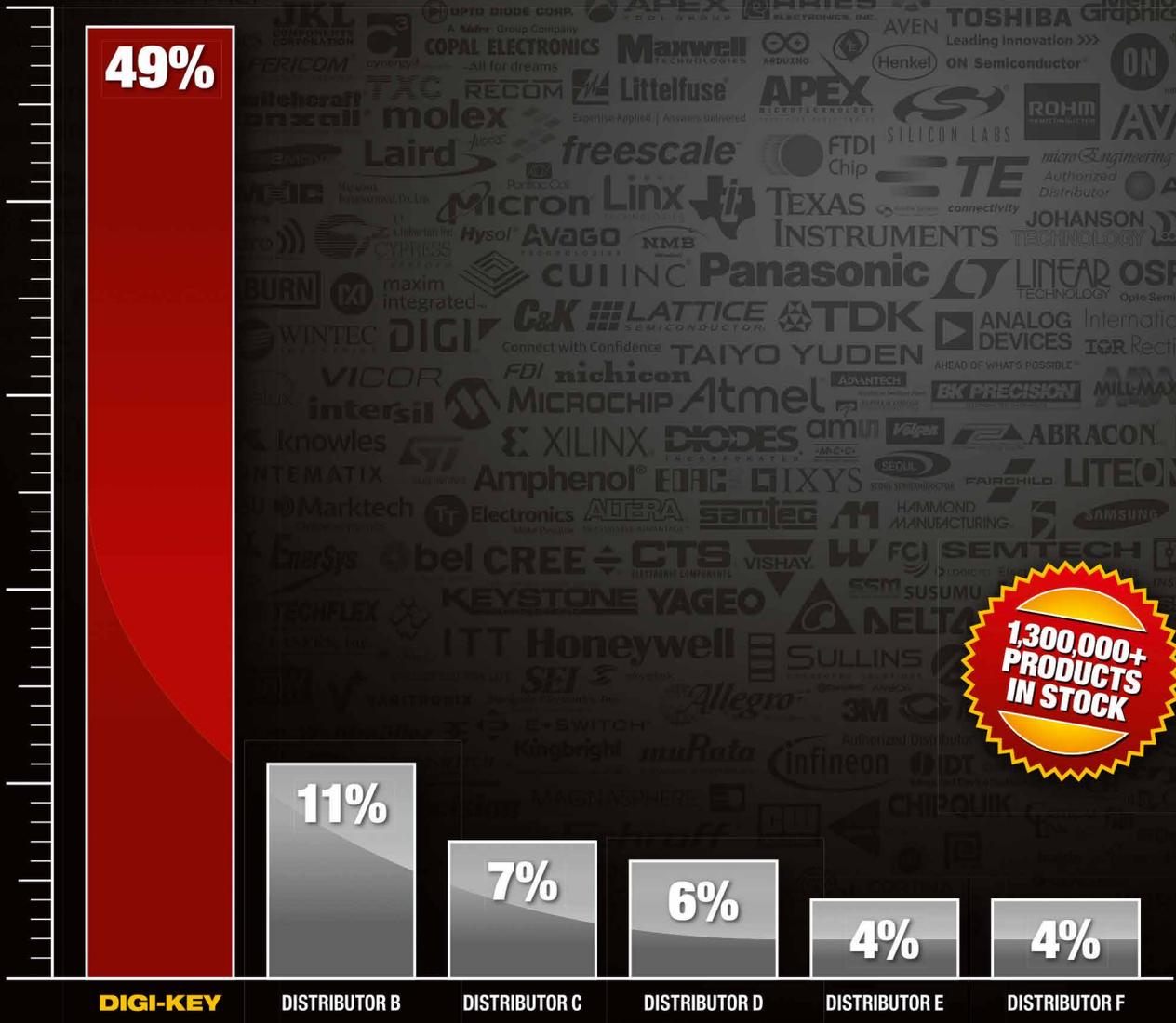
Manufacturing: Potting Processes for LED Modules

Technology: Optimization of Thermal Management

Tech-Talks BREGENZ: Dr. Biing-Jye Lee

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# In the Framework of Photonics

Swiss Photonics hosted the Annual General Meeting (AGM) of the European Photonics Industry Consortium (EPIC) in Zurich, Switzerland on April 21<sup>st</sup> and 22<sup>nd</sup>. There were more than 150 C-level attendees there who presented their views on the field of Photonics.

In respect to the SSL industry, Carlos Lee, Director General at EPIC told LED professional, "The scope of EPIC encompasses all photonics technologies, including lighting. Zumtobel sits on the EPIC board of directors and key players, such as Lumileds, guide EPIC towards priorities with regards to SSL. Being on the board of ISA (International SSL Association) enables EPIC members to connect globally and our partnership with LED professional and the LpS event allows us to tackle technology from emerging markets, such as lighting in general applications, horticulture and automotive lighting as well as other relevant topics."

Director Murphy Lin from the Taiwanese Photonics Industry and Technology Development Association (PIDA) presented an overview of the global Photonics market and also highlighted the recent developments in the Taiwanese market place. PIDA, with whom LED professional has a long-term partnership, has been focusing on Industry Research, Information Service, International Cooperation, Publication and Promotion Efforts since 1993.

PIDA is clustering the Photonics field into the following areas: LED & Lighting Application, Laser, Flat Panel Display, Photovoltaic, Optical Storage, Precision Optical Lens & Module, Bio-photonics, Optical Fiber Communication and Image Sensor & I/O Devices.

This year, the worldwide production value in these areas will reach approximately USD 650 billion with an estimated compound annual growth rate (CAGR) of approximately 6% between 2014 and 2018. It's a decline of 4% in CAGR compared to the earlier investigated years from 2010 to 2014. Photovoltaic, Flat Panel Display and Bio-photonics are the most dominant industry sectors where SSL only counts for approximately 9% of the total production volume.

For the next two years PIDA expects the highest growth rates in: Image Sensor (10%), LED & Lighting Application (9%), Optical Fibre Communication (9%), Photovoltaic (8%) and Laser Light Sources (8%). The Taiwanese market sees the LED sector as being in sixth place in regards to production volume. But with an expected growth rate of 20% it will be in third place together with Laser Diodes in the top scale of the most important sectors in the Photonics industry. With a global share of approximately 10% of the total photonics production value, the LED & Lighting Application sector has room to expand. This is exactly what the estimates are showing for the next few years.

On a different note, issue 55 of LED professional Review covers Glass Ceramics, the TTB with Dr. Lee from Epistar, the post-show report from the Light+Building in Frankfurt, and articles on Thermal Management, LED Potting Methods and Quantum Dots.

As always, please feel free to contact the LED professional team to send us your comments!

Yours Sincerely,

Siegfried Luger  
Publisher, LED professional  
Event Director, LpS 2016

PS: Early Bird Tickets for the LpS are available until July 1<sup>st</sup>. [www.LpS2016.com/registration](http://www.LpS2016.com/registration)

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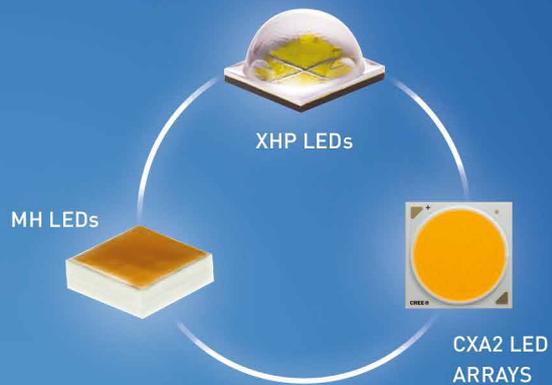
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### Dr. Nisa Khan

Dr. Nisa Khan is the author of *Understanding LED Illumination* (CRC Press, 2013).

She received her Bachelor's degree in Physics and Mathematics, and her Master's and Ph.D. degrees in Electrical Engineering. Her 32-year career includes work at Honeywell Solid-State Research Center and AT&T Bell Labs (now Nokia) where she conducted pioneering research on 40-Gb/s optoelectronic and photonic devices. Since 2006 she has been working on LED lamps suitable for general lighting.

## LFI 2016 TOUTS LED LIGHTING AND DIGITAL CONTROL TECHNOLOGY TRANSFORMATION

The 27<sup>th</sup> Annual LightFair International (LFI) conference was dominated by LED lighting coupled with internet-based control via wireless networks that continues to proliferate in today's world. The world is increasingly becoming drenched with Internet of Things (IoT) discussions, demonstrations and for some, a certain level of implementation. Electric lighting transformed our society for over 100 years, boosting our mood and association with the environment, culture, productivity, and economic conditions. Such enormity pales in comparison to an unprecedented revolution that LFI describes as "Light and Technology in a New Language!"

The LED lighting story started with the drastic lm/W advantage, followed by lm/\$ advantage. While both of these factors continued to improve without sacrificing color quality to a significant degree, the lighting industry still remained hesitant. The advantage that really caught on now is making LED lighting intelligent so that it provides the most suitable lighting automatically throughout the day for a variety of circumstances and each LED lamp can make IoT optimal and affordable for every household. The story is amazing!

From the business perspective, this sounds as colossal as it is meant to because light is virtually everybody's consumable resource; and if this resource comes with energy and cost savings along with enhanced lifestyle as well as health, who could argue against it? However, such painted pictures almost never turn out to be as good as they first appear.

The LED lighting overtaking story has two sides. Most industry participants at LightFair, media included, are touting the great benefits of LED lighting in terms of color tunability, synergy with IoT, higher efficacy, CRI over 95, as well as the freedom to design luminaires to fit various architectural forms that aren't possible with traditional lamps. These include declarations from Osram representatives that their LED tubular and nostalgic vintage glowing lamps offer a slew of these benefits while offering the exact same light distribution as their fluorescent and incandescent counterparts do; speaker Ms. Cohen (Eaton Lighting) in the seminar on revolution in lighting

control systems claimed that the beautiful, tunable LED troffers currently available should not be installed without their light adjustment control units that would offer substantially higher value; Dr. DiLaura (Acuity Brands) explained in "A History of Light and Lighting" seminar that LED lamps now produce light in all different directions just as traditional lamps by placing the tiny individual LEDs in various directions.

LEDs do offer color tunability that covers a broad range of CCT mimicking daylight, much improved CRI, as well as form factors that allow creative architectural lighting. While these are inherent and unique benefits of solid-state lighting, current LEDs have issues not suitable for human-centric lighting and vision developed through evolution. Ms. CJ Brockway, in "The Dangers of Over-lighting", pointed out some adverse effects of glare and non-uniform illumination for humans, plants, and our ecosystem. LEDs still face wide tunability variabilities due to the persisting binning challenge that require different algorithms to custom-tune CCT for LED luminaires from manufacturers as revealed by Mr. Hamilton from Ketra who further discussed the notable impact of blue-light hazard. We should also assess whether the vast amount of data managed by IoT actually has any significant benefit while compromising personal security. Mr. Charles Knuffke (Wattstopper) and Mr. Shinichi Yamamura (Minebea) pointed out the need for glare reduction and tuning consistency improvements in LED luminaires. These challenges may very well account for why Princeton University is hesitant in replacing their traditional lighting with LED counterparts, experiencing notable objections from many professors against LED upgrades. As presented by Ms. Ziegenbein (Hartranft Lighting), the DOE disclosed that while the LED luminaire shipments account for 46% of all lighting systems in 2015, the total market adoption for LEDs was only 3% in the US. Ms. Goyette of "Lighting Design and Specification" magazine in Canada, supported my stance that not enough people are talking about the LED challenges, clarifying where they come from and what we need to do about them. LED lighting's mainstream sustainability can only be accomplished by attending to these. ■

N.K.

# Philips Fortimo LED Strips

0.5ft 550lm, 1ft 1100lm, 22" and 24" 2200lm 1R LV3 Modules



Fortimo LED Strip systems are ideal for use in narrow width luminaire designs for architectural applications that were not possible with fluorescent lighting before. Fortimo LED Strips offer best-in-class module efficiency of up to 163lm/W.

## Features

- Narrow width (20mm)
- High CRI options (CRI90) and 3 SDCM color consistency
- Variation of color temperatures (3000K, 3500K, 4000K and 5000K)
- Zhaga compliant

## Applications

- Office/Industry/Retail

## Benefits

- Slim width enables optimized luminaire design and new form factors
- High color rendering and excellent color consistency brings linear LED lighting to the next level for quality of light
- 5-year limited system warranty with Philips Advance Xitanium LED Drivers\*

\* View limited warranty at [usa.lighting.philips.com/connect/tools\\_literature/warranties.wpd](http://usa.lighting.philips.com/connect/tools_literature/warranties.wpd) for details and restrictions.

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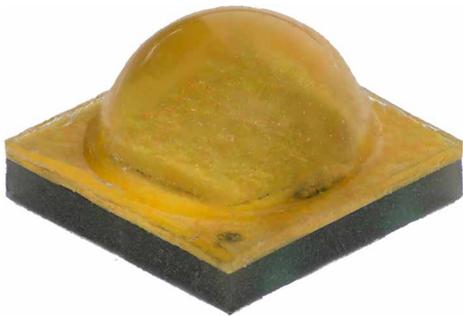
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## XP-G3 LED Delivers More than 205 LpW

Cree introduces the XLamp® XP-G3 LED, delivering 31 percent more lumens and 8% higher lumens-per-watt (LPW) than the industry-leading XP-G2 LED. Leveraging key elements of Cree's SC5 Technology™ Platform, the high-power XP-G3 LED improves the lumen density, voltage characteristics and reliability of previous XP-G generations. This performance enables lighting manufacturers to deliver differentiated solutions at lower system costs for applications such as roadway, outdoor area, spot and high-bay lighting.



**Cree's new XP-G3 LED improves lumen density, voltage characteristics and reliability of previous XP-G generations**

"We are designing a new series of 130 lumens-per-watt high performance streetlights and the choice to use the new Cree XP-G3 LED was clear," said Wilbur Tarn, director of OrangeTek. "The XP-G3 LED delivers high efficacy and high reliability in the familiar XP-G footprint, allowing us to modify elements of an existing design to shorten our design time by half."

Cree pioneered the industry-standard high power 3535 form factor with the XP platform and continues to deliver breakthrough performance with the XP-G3, achieving over 205 LPW at 350mA and up to 863 lm at 2A. Extending Cree's leadership in reliability and lumen maintenance, the XP-G3 LED has 6,000 hours of LM-80 data immediately available that provides L90 lifetimes well beyond 50,000 hours, even at an extreme 105°C, 1500 mA test condition.

"Cree is committed to R&D that enables our customers to deliver the best system value in the market with high-power LEDs," said Dave Emerson, Cree vice president and general manager, LEDs. "The XP-G3 is the first LED in its class to shatter the 200 LPW barrier, setting a new benchmark for the

XP-G class of LED and joining Cree's other high-power LEDs that deliver this level of performance."

The new LEDs are characterized and binned at 85°C, available in ANSI White, EasyWhite® 3- and 5-step color temperatures (2,700 K - 6,500 K), and CRI options of 70, 80 and 90. ■

## 7-Colors on a Single Emitter from LED Engin

LED Engin announces the world's first 7-color, high power LED to be produced on a single emitter. The compact LZ7-04MU00 emitter enables the design of stage or architectural lighting that produces sophisticated effects over the full color spectrum.



**LED Engin's LZ7-04MU00 adds phosphor-converted amber, cyan and violet to conventional RGBW**

Its RGBW die are complemented by phosphor-converted (PC) amber, cyan and violet to provide richer, wide-ranging color effects. PC amber delivers the same saturation as regular amber but with 5 times the flux at temperature, cyan fills the spectrum gap between blue and green, and violet enables black or crisp white lighting effects. Typical stage and studio applications include moving heads with zoom optics and round wash lights. In architectural lighting, the emitters enhance the performance of everything from static lights to linear wash lights.

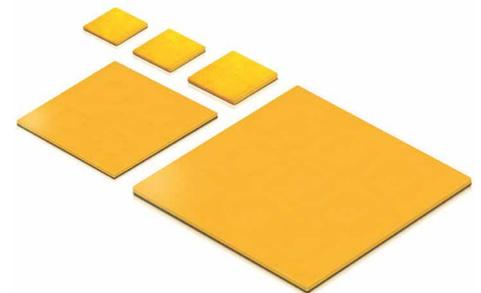
The flat lens LZ7 emitter, which has a 7 x 7 mm footprint, comprises 7 individually addressable die assembled onto a 3.8 mm light emitting surface and capped with a low profile glass lens. This ultra-thin construction means that mixing rods can be positioned as near as possible to the die to maximize coupling efficiency

LED Engin's proprietary multi-layer, multi-channel substrate technology underpins the performance of the LZ7. The substrate's thermal resistance is only 1.4°C/W and it dissipates up to 20 W effectively. RGBW individual dies can therefore be driven, one at a time, to a maximum current of 1.5 A. Alternatively, a single amber, cyan or violet die can be driven at up to 1 A. In a third operating mode, all dies can be driven simultaneously at 850 mA.

LED Engin CEO, David Tahmassebi, said, "There is growing demand for stage lighting that's capable of creating ever more dazzling and complex effects. Our latest 7-color technology breakthrough means that fixture designers can deliver these without suffering the design complexity experienced when using multiple single-die LEDs." ■

## Samsung Introduces Full Line-up of CSP LEDs

Samsung Electronics introduced a full line-up of chip-scale LED packages (CSP), including 0.6 W class and 3 W class packages, CSP arrays, and PoW (Phosphor on Wafer) packages.



**Samsung's portfolio of chip-scale packages**

A wide range of CSP components includes packages with different operating wattage levels, as well as CSP arrays and Phosphor-on-Wafer packages.

Samsung's CSP technology significantly scales down the size of a conventional LED package by combining advanced flip chip technology with phosphor coating technology, thereby eliminating any need for metal wires and plastic molds. This shift enables more flexible and compact designs when manufacturing LED lighting modules or fixtures, and lowers the production and operational costs of LED lighting systems. Samsung's CSP products also allow for



## Street Lighting ( Developing / Material: Silicone )



**LL01CR-CQW45150L100**  
DxWxH(mm) 99.7x110.5x32.78  
FWHM 45x150°  
Cree CXA3050  
Citizen CLL040/042  
Lumileds L2C1-1211



**LL01CR-CQW60155L100**  
DxWxH(mm) 99.7x110.5x30.98  
FWHM 60x155°  
Cree CXA3050  
Citizen CLL040/042  
Lumileds L2C1-1211



**LL01CR-CQW90155L100**  
DxWxH(mm) 100x110.5x31.67  
FWHM 90x155°  
Cree CXA3050  
Citizen CLL040/042  
Lumileds L2C1-1211

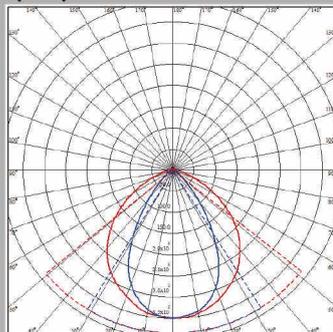
## Indoor Lighting

### Linear Lens ▼



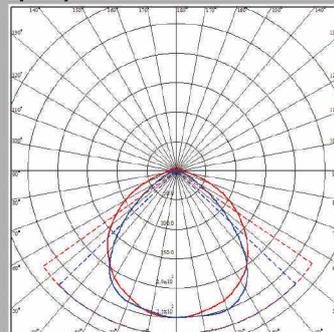
**LL01NI-CROxxL06**  
DxWxH(mm) 286x32.4x6.7  
FWHM 60° 90°  
Seoul 5630 LG 5630  
Nichia 757D

(60°)



-C0:0-180 -C1:90-270

(90°)



-C0:0-180 -C1:90-270

### Lens Application ▼



## Commercial Lighting

### Convex Lens ▼



**LL12ZZ-CRC90L19**  
DxWxH(mm) 50x50x3.8  
FWHM 90°  
Edison 3030  
Lumileds Luxeon 3030  
Nichia 757D

### Multi Lens ▼



**LL12ZZ-CRCxxL19**  
DxWxH(mm) 50x50x6.3  
FWHM 25° 55°  
Edison 3030  
Lumileds Luxeon 3030  
Nichia 757D

flexibility in adjusting the size of the light-emitting surface and its associated luminance level, to meet the diverse requirements of a wide variety of lighting applications including bulbs, spot lighting, downlighting and street lighting.

“Our new CSP products overcome what had been significant performance limitations of conventional LED packages. By expanding our CSP line-up, we expect to provide greater value to the LED lighting market, enabling new possibilities in LED lighting and giving our customers greater design flexibility,” said Jacob Tarn, Executive Vice President, LED Business Team, Samsung Electronics. “We are aggressively innovating through the introduction of well-differentiated LED components, while further strengthening our presence in the LED marketplace in terms of technology and cost.”

The new CSP line-up has been fortified with a wide range of operating current options from 0.6 W to 3 W and even 10 W LED packages. The new packages complete Samsung’s CSP technology roadmap, which was announced at LIGHTFAIR International 2015 when the company’s CSP technology commercialization plan was unveiled.

#### Mid-power, 0.6 W class CSP LED packages - LM101A & LM102A:

The LM101A and LM102 are Samsung’s new mid-power CSP packages for LED lighting. Based on advanced flip chip technology, the LM101A and LM102A feature ultra-slim form factors and simple package structures that enhance their cost competitiveness. Each offers two voltage options - 3 V and 6 V, which make the packages applicable to numerous applications including bulb, high bay lighting, downlighting and spot lighting.

Along with enticingly small form factors, the mid-power CSP LED packages also provide wide beam angles, therefore delivering even greater design flexibility. Samsung’s LM101A and LM102A packages are available in full color temperatures with three color rendering index options from CRI 70 to CRI 80 and CRI 90.

#### High-power, 3 W class CSP LED package - LH181A:

The LH181A is a high-power CSP package that features approximately 12 percent higher luminous flux at a maximum current of 1.5 A, compared to Samsung’s 3 W class ceramic-based high-power LED package.

The LH181A offers a high luminous flux, typically at around 162 lm/W (@ 350 mA, Ra70, 5,000 K).

Each LH181A measures 1.91x1.91 mm, which is about 30 percent smaller than Samsung’s ceramic-based LED solution. The package’s ultra-small size enables much smaller lighting designs and better lm/\$ (lumens per dollar) value that can be especially useful in outdoor and spot lighting applications.

The LH181A provides a wide beam angle of 140 degrees making it also applicable to street lighting by adding a lens as a secondary optic solution.

#### CSP Arrays - LH204A & LH309A:

Samsung’s CSP arrays, the LH204A and the LH309A, are high-power LED solutions with an operating wattage range from 5 W to 10 W. The LH204A is a 2x2 array of CSP LED chips that delivers 12 V at a 5 W class operating wattage, while the LH309A is a 3x3 chip array offering 26 V at a 10 W class operating wattage.

The CSP arrays provide high light quality by adhering a single phosphor to the FX (flexible) circuit board on which tiny CSP LED chips with low thermal resistance are arranged. The use of a thin flexible-film FX circuit board accentuates the thin design of the arranged CSP LED chips. The CSP arrays are suitable for spotlighting applications where high light quality is required from a single light source.

#### Next-generation CSP solution - PoW (Phosphor-on-Wafer) LED package:

Samsung’s Phosphor-on-Wafer (PoW) LED package technology embraces the advantages of CSP LED packaging, while overcoming limitations of cost reduction by upgrading the chip manufacturing process through the use of 8-inch GaN-on-Si wafers instead of 4-inch sapphire wafers. This transition will enable a higher quality CSP LED package by eliminating the chip rearrangement process. The reason for this is that the phosphors can be directly coated on the surface of the GaN-on-Si wafers before being diced, while sapphire wafers have to be cut into chips first and then rearranged to be coated with phosphor.

By simplifying the LED component manufacturing process and improving

LED package quality, the PoW LED package technology is expected to contribute significantly to the growth of the LED lighting industry.

Samsung already applied its PoW technology to 4-inch wafers in flash LED packages for mobile devices several years ago. Samsung also plans to utilize the PoW technology for its new CSP product line-up for lighting applications by the end of this year. ■

## Lumileds Luxeon HR30 for Superior Resistance to Harsh Environments

Lumileds introduced the Luxeon HR30 LED, a mid power device that withstands harsh chemical environments and is designed with robust packaging and industry-best materials to operate for over 100,000 hours of continuous operation. This LED addresses the tremendous need for dependable lighting that will operate in hazardous environments (such as chemical plants, power generation facilities and natatoriums) and be able to withstand extremes of temperature and operating current.



#### Lumileds claims the Luxeon HR30 to be the most robust mid power LED ever designed

“The Luxeon HR30 is the only LED in its class to provide a service life in the 100,000 hour range while withstanding corrosive elements like sulfur and chlorine,” said Matthew Everett, Senior Product Director for Luxeon Mid Power Products. The LED’s chemical resistance is partially attributed to its gold-plated leadframe and its optimized materials package. The Luxeon HR30 has demonstrated strong performance in chemical resistance tests such as IEC68-2-43 (15 ppm): delta LOP < 10%, delta u’v’ < 0.006 after 21 days. “Engineering for chemical resistance is all about selecting the best materials and then testing those materials under harsh

conditions. We have leveraged our expertise in materials science and lumen maintenance to produce the industry's most robust mid power LED," said Everett.

The Luxeon HR30 produces 125 lumens at 134 lm/W when driven at 150 mA at 4,000 K and 70 CRI. The LED is available at color temperatures of 4,000 K, 5,000 K and 5,700 K at 70 CRI and 2,700 K, 3,000 K, 4,000 K and 5,700 K at 80 CRI. ■

## Luxeon 2835 Delivers Perfected Performance, Built on a Proven Legacy

Lumileds introduced the perfect upgrade for an industry standard LED package, the Luxeon 2835 Line. Luxeon 2835 LEDs are available in five configurations of light output and string voltage and ESD protection to meet a variety of illumination application needs including retrofit lamps, downlights and troffers. "The LED retrofit bulb and other application segments are taking off right now. We decided to optimize for each application requirement via different offerings within the Luxeon 2835 Line," explains Matthew Everett, Senior Director of Mid Power Products.



**Lumiled's Luxeon 2835 Line for cost-effective retrofit lamps, downlights and troffers**

To cater to the market, the Luxeon 2835 is offered in two light output ranges: Luxeon 2835C for higher efficacy and an industry-leading 240 mA maximum drive current with 3 V and 6 V options and Luxeon 2835E for the most cost-effective retrofit lamp designs with 6 V and 9 V options. Makers of low cost retrofit bulbs targeting soft white (2,700 K, 80 CRI) will benefit from the Luxeon 2835E 9 V, which produces 72 lumens at 134 lm/W when driven at 60 mA. For entry level bulbs, a lighting manufacturer might choose the Luxeon 2835E 6 V, which produces 49 lm with the same efficacy. Dimmable bulbs,

LED candles and downlight manufacturers might choose the Luxeon 2835C 6 V, which produces 103 lumens at 138 lm/W in 2,700 K and 80 CRI when driven at 120 mA. A key advantage of all Luxeon 2835 LEDs is their ability to be driven at double these reference drive currents to achieve even higher flux and use fewer LEDs per bulb.

For designers of mid-range troffers, linear fixtures and downlights, the Luxeon 2835C 3V is available in two versions, one with a TVS (Zener) and one without. The 2835C 3V LED without TVS produces 58 lumens at 156 lm/W in 4,000 K and 80 CRI when driven at 120 mA.

The Luxeon 2835 Line is offered across a CCT range of 2700 K - 6500 K at 70 and 80 CRI. All Luxeon 2835 6 V & 9 V LEDs are hot-color targeted to ensure the color remains within ANSI bin specifications at typical application conditions. Micro color binning allows customers to easily create 3, 4 or 5 step MacAdam Ellipse kits. ■

## Luxeon 3535L HE Plus for Most Reliable, High Efficiency Troffers

Lumileds launched Luxeon 3535L HE Plus, the instant upgrade to the highest efficacy, in a familiar 3535 form factor. This mid power part satisfies the need for efficacy approaching 200 lm/W at the LED level and 160 lm/W or greater at the luminaire level. "In one of the industry's most popular formats, customers are requiring the highest efficiency with all of the fantastic features delivered by our Luxeon 3535L Line," said Matthew Everett, Senior Director of Luxeon Mid Power Products.



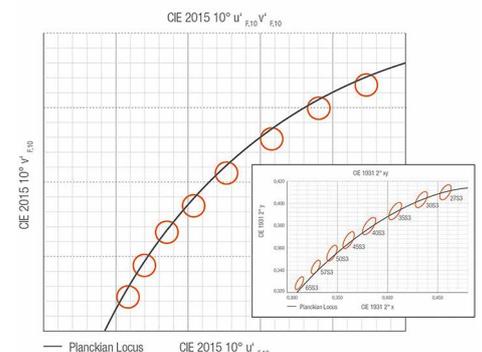
**With efficacy levels approaching 200 lm/W, the Luxeon 3535L HE Plus delivers the most reliable and efficient uniform light source for troffers, high bay and low bay fixtures**

Only Lumileds has proven reliability for its mid power LEDs that rival that of high power products. For instance, LM-80 data for the Luxeon 3535L at 85°C and 200 mA after 10,000 hours indicates the LEDs will maintain 90% of lumen output after seven years of continuous operation (projection using TM-21). In addition to outstanding lifetime performance, Everett noted a better color over angle with the Luxeon 3535L emitter versus its competitors, which enables better color consistency over the LED's useful life.

Typical performance of the Luxeon 3535L HE Plus at 4,000 K and 80 CRI is 52 lumens at 100 mA drive current and 186 lm/W or 34 lm at 65 mA drive current and 194 lm/W. The 3 V parts are initially available in color temperatures of 2,700 K, 4,000 K and 6,500 K and 80 CRI. They are tested at 100 mA and are 1/7<sup>th</sup> ANSI color binned. ■

## Soleriq S 13 Gen 3 - Osram Presents 10° Binning for White LEDs

New "TEN°" binning from Osram Opto Semiconductors provides the basis for unprecedented color consistency for white LEDs which are used for example as single-LED light sources in spotlights and downlights. To achieve this the current standard CIE 1931 2° xy color space has been supplemented with CIE 2015 10° u'v', recently developed by the International Commission on Illumination and implemented by Osram Opto Semiconductors as 10° binning. In the third generation of the Soleriq S 13, "TEN°" is available on the market as an additional feature since March 2016.



**Comparison of Osram's "TEN°" binning in the 2015 10° u'v' color space with the standard 3 SDCM binning in the CIE 1931 2° xy color space (inset)**

“TEN°” is the name of the new white binning from Osram Opto Semiconductors. In contrast to the established CIE 1931 2° color space, the recently developed CIE 2015 10° corresponds much better to the physiological perception of color - hence 10° binning. This subject is of particular interest for achieving uniform illumination from spotlights and downlights in which individual white CoB LEDs are primarily used. This new binning will be used for the first time in the new generation of the Soleriq S 13 and will provide optimum color consistency in applications. “Obviously these Soleriq LEDs comply with current industry standards and continue to be completely compatible with existing white groupings. “TEN°” binning is simply an additional property - and an extremely useful one”, said Alexander Wilm, Key Expert for General Lighting at Osram Opto Semiconductors.

If Soleriq LEDs that have been binned on the basis of these latest findings are installed, for example, in spotlights it will be much easier to avoid differences in light colors compared with products grouped according to the old CIE 1931 2° standard. This, in turn, means fewer process stages for luminaire manufacturers which would otherwise be necessary because of different white color impressions in the ultimate application.

The starting point for development activities at Osram Opto Semiconductors was that two LEDs with the exact same color coordinates in the CIE 1931 2° color space could still exhibit noticeably different white tones. One reason is that the small rods that are responsible for color perception in our eyes are not evenly distributed. This leads to different color perceptions even with LEDs in 1 SDCM binning with conventional metrics. This problem has been known and researched by scientists for many decades. However the results of their research have never been applied to general lighting. Osram Opto Semiconductors has now changed all that. ■

## Homogeneity, Efficiency Colors, Compactness - the DURIS® Family

Whatever your needs - the DURIS® family will meet them. For example the DURIS® E, the perfect solution for cost-conscious applications. Or the DURIS® P 5 and

DURIS® P 5 colors for high-quality, professional indoor and outdoor lighting applications. DURIS® S 5, the mid-power LED, stands for flexibility and efficiency, and with DURIS® S 8, the highpower LED, we are setting standards in compactness for indoor illumination.



Osram Opto's DURIS® E low- and mid-power LED portfolio

Despite its small footprint, there is maximum power inside the DURIS® E:

- Compact light source in cost effective PLCC package
- Stable brightness over lifetime
- Compact size for perfect second-board reliability
- Full portfolio supplier providing CRI 70, 80, 90 high efficacy in 5630 package
- Low-/mid-power LEDs with wide beam angle for homogenous light distribution

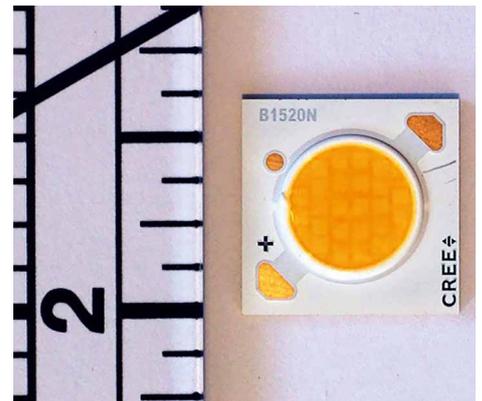
Experience the various possibilities of the DURIS® E:

- Applications in indoor general lighting, e.g. Residential, Office
- Linear light including fluorescent replacement lamps
- Area lights including troffer and panel lights
- Signage e.g. channel letters
- Industry applications e.g. white goods

The DURIS® E, a low- and mid-power LED portfolio from OSRAM Opto Semiconductors, is ideal for efficient and homogeneous lighting applications. The combination of a small/medium lumen package, a wide beam angle and a compact footprint is perfect for uniform light distribution. The portfolio meets the user requirements for cost conscious applications. That's why they are the preferred choice for replacing fluorescent tubes or light bulbs in the field of home, shop and office. ■

## New Cree XLamp CXA2 High Density LEDs Double Lumen Output

Cree continues to break performance barriers with the introduction of Cree® XLamp® CXB1310 and CXB1520 High Density LED arrays. Incorporating elements of Cree's SC5 Technology™ Platform, the new LEDs deliver the highest lumen density at 6mm and 9mm - the most lumens in the industry for their LES [light emitting surface] sizes. The advancement enables radically new and differentiated LED lighting form factors for applications like track lights, lamps and downlights. For example, the CXB1520 LED packs the lumen output of seven 60-watt replacement lamps into an area much smaller than a dime, allowing lighting manufacturers to put more light where it is intended at a lower system cost.



Cree's CXB1520 is the first CoB LED that delivers over 6,000 lumens in 9mm LES enabling better light experiences

“The CXB1310 High Density LED array delivers an impressive amount of light in a small package,” said Massimo Parravicini, R&D director of Reggiani Illuminazione. “The high lumen density of the CXB1310 LED will allow us to offer LED designs with performance and form factors previously impossible.”

The high performance of the CXA2 High Density LED arrays allow lighting manufacturers to reduce thermal, mechanical and optical costs at the system level. For example, when combined with a 74mm diameter optic, the 3,000 K, 80 CRI CXB1520 High Density LED array delivers over 50,000 candela in a 10-degree beam while drawing only 40 watts. This high lumen density allows lighting manufacturers to deliver the performance of a 70 W ceramic metal halide (CMH) PAR38 lamp through a

much smaller PAR20-size optic using 43% less power. The CXB1310 High Density LED array delivers up to 3,200 lumens in a 6 mm LES, allowing similar reductions in size and power from traditional light sources.

“The CXB1520 High Density LED allows us to deliver downlights that provide up to 2700 lumens with just 28 watts in a very small 4” trim platform. What was previously only possible in much larger platforms with much higher wattage requirements is now made possible in our VF Series Specification Grade Luminaire Downlight product line using Cree’s CXB1520 High Density LEDs,” said Justin Weaver, Vice President Engineering, LF Illumination. “The very high efficacy of the CXB1520 High Density LED also allows us to move many of our products that at one time were only possible with active cooling solutions to passive solutions, simplifying our design and lowering our system costs significantly.”

Offering the industry’s best color consistency for designs that use only one LED, Cree XLamp CXA2 High Density LED arrays are characterized and binned at 85°C, available in 2-, 3- and 5-step EasyWhite® color temperatures (2,700 K - 6,500 K), and CRI options of 70, 80 and 90. The CXB1310 and CXB1520 LEDs have LM-80 long-term test data available immediately, delivering reported L90 lifetime projections of at least 36,300 hours at 85°C and 105°C.

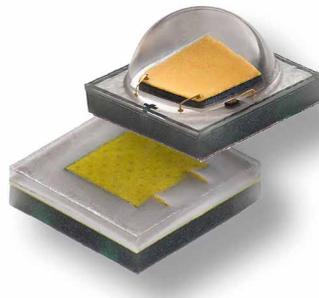
“Cree pioneered high lumen density LED arrays, and we continue to push the boundaries of LED performance, consistently achieving what no other LED manufacturer has been able to achieve,” said Dave Emerson, vice president and general manager for Cree LEDs. “The industry-leading performance of the new CXA2 High Density LED arrays allows our customers to develop differentiated products that deliver high performance and energy savings through better LED technology.”

The CXA2 High Density LED arrays are available in the same form factor as the CXA LED arrays, allowing the use of existing optics, holders and drivers. The CXA2 High Density LED arrays are also UL-recognized and feature a level 4 rating. Product samples are available now, and production quantities are available with standard lead times. ■

## Cree Boosts XLamp XP LEDs Performance

Cree continues to innovate to deliver industry-best performance in its high-power XLamp® XP-L and XP-G2 LEDs.

By leveraging key elements of Cree’s SC5 Technology™ Platform, the XP-L and XP-G2 LEDs now provide up to nine percent more lumens and lumens-per-watt than previously available. These enhancements allow lighting manufacturers to quickly increase performance for existing designs without any additional investment or requalification.



**Cree’s new generation of XLamp® XP-L and XP-G2 LEDs will deliver 9% higher efficacy and L90 greater than 36,000 hours**

“We originally selected the XP-G2 LED for our street lighting products because of its high performance and proven reliability,” said Dante Cariboni, CEO, Fivep SpA (Cariboni Group). “The brighter and more efficient XP-G2 LED will allow us to improve the performance of our products without changing the design.”

“Cree has a history of introducing significant LED advancements, like our Extreme High Power LEDs, that enable our customers to achieve industry-leading lighting system performance and cost,” said Dave Emerson, vice president and general manager for Cree LEDs. “We also understand that our customers have invested significant time and resources in existing designs that incorporate Cree XLamp® LEDs. The higher performing XPL and XPG2 LEDs are examples of how Cree delivers innovation that our customers can use immediately to improve existing designs.”

Cree pioneered the industry-standard form factor with the XP platform and has continued to deliver breakthrough performance to the platform. Sharing the same 3.45 x 3.45 mm footprint, the XLamp XP-L LED delivers up to 1150 lumens, while the XLamp XP-G2 LED delivers up to 586 lm,

both at 85°C. Reflecting the excellent long-term reliability of the XLamp XP platform, both the XP-L and XP-G2 LEDs have 10,000 hours of LM-80 data available at 105°C, delivering reported L90 lifetimes of greater than 36,000 hrs, which is less than 10 percent light loss after four years. ■

## Lower System Cost in the Proven Ceramic XQ Package

The XLamp XQ-A LED brings a mid-power, cost-effective option to the proven, compact ceramic XQ package, enabling lighting manufacturers to quickly expand their product portfolio by leveraging a common XQ design. Unlike plastic mid-power LEDs, the ceramic-based XQ-A LEDs are designed to deliver the long-term calculated lifetimes of Cree’s other high-power LEDs. Available in white and color, the XQ-A LED delivers up to 89 lm at 85°C.



**The XQ-A LED is the smallest LED building block available for designs that use white and color LEDs**

With a broad range of color options and optical symmetry, the XQ-A LED is the smallest LED building block available for designs that use white and color LEDs.

“The introduction of the XQ-A LED gives us more options to increase the capability of our machine vision and industrial LED lights using the same compact XQ package that we know and like,” said Matt Pinter, co-founder and lead design engineer for Smart Vision Lights. “Unlike mid-power color LEDs, the compact, ceramic-based XQ-A LED will allow us to put two, three or even four LEDs under our new silicone lens technology where we could only use one LED before. This generates more light for industrial applications without compromising lifetime.”

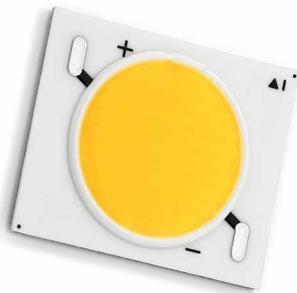
The ceramic XQ-A LED delivers lighting-class reliability, quality and long-life performance comparable to Cree's other ceramic high-power LEDs such as the high performing XP and XT. The new LEDs leverage the proven XQ platform to provide optical symmetry, consistency across all colors and tiny 1.6 mm footprint to improve color mixing and simplify the production process for lighting manufacturers.

"At Cree, we continue to deliver innovative products that enable our customers to differentiate their products in the marketplace," said Dave Emerson, vice president and general manager for Cree LEDs. "The ceramic-based XQ-A LED family allows designers to offer high quality solutions that do not compromise lifetime or affordability."

The XQ-A delivers up to 89 lumens and is characterized at 85°C. It is available in white color temperatures ranging from 2700 K to 6200 K and CRI options of 70, 80 and 90. The LED is also available in red, red-orange, PC amber, green, blue and royal blue. ■

## Sharp Launches New High Efficiency COB LED Range

Sharp Devices Europe (SDE) has announced a new range of high-performance Mini and Mega Zenigata COB LEDs with greater efficiency and enhanced hot lumen performance.



**Sharp's new high efficiency COB LED range offers high quality of light and hot lumen performance**

### More lumens, hot and cold:

Sharp Devices Europe (SDE) has launched a new range of COB LEDs with outputs ranging from 600 to 6,000 lumens. Available in the popular Mini and Mega Zenigata footprints, the new HD6 and BF6

series LEDs from Sharp are highly efficient, achieving up to 153 lm/W.

Advances in Sharp's die-level technology together with the global technology giant's package expertise are what made this latest round of efficiency improvements possible. By retaining the popular Mini and Mega Zenigata form factors, Sharp has also ensured backwards compatibility and simplified mechanical integration for its customers. The new HD6 Mini Zenigatas are 12x15 mm with an 8mm light emitting surface (LES). The BF6 series Mega Zenigatas are manufactured on a 20x24 mm substrate with a 15 mm LES. At up to 2,500 lm from the 8 mm LES, the new Mini Zenigata packs quite a punch.

"The Mini and Mega Zenigatas are available not only in Ra80 and 90 versions, but also in a range of colour temperatures. Together with the efficiencies these new models are achieving, we can offer high colour rendering performance across a vast range of applications," said Sharp Devices Europe LED Sales Manager Alberto Quaglia. "Our new COB LEDs also stand out because of their superior hot lumen performance. Most LED manufacturers specify cold performance, but all LEDs see a dip in intensity once they reach operating temperatures in the luminaire. The new Mega and Mini Zenigatas offer higher output under real-world conditions."

### Continued focus on colour quality:

Sharp has always focused on colour quality throughout its LED line-up. The new LED models are no exception. Production is binning-free yet still yields emitters that fall within a 3-step MacAdam ellipse as standard for all the new LEDs. ■

## Everlight Electronics Improves Efficiency of its 5630 LED Series

Everlight, a leading player in the global LED and optoelectronics industry, announces an ultra-high efficiency version of its low-mid-power 5630 package series, the 5630 HE KK7D-ELB, available now. The 5630 HE KK7D-ELB series (0.2 W) achieves 210-220 lm/W to fulfill the high luminous performance demands of professional, commercial and industrial lighting applications.



**Everlight's 5630 High Efficiency (HE) KK7D-ELB series now achieves 210-220 lm/W and is Everlight's highest efficiency product**

With the rise of energy-saving efforts worldwide and improvement of applications using LEDs as next-generation light sources, more emphasis is put on the performance of LED lighting components than ever before. Everlight breaks through technical barriers to provide its highest efficiency product ever. The 5630 HE KK7D-ELB (0.2 W) achieves 210-220 lm/W (5,000 K) and excels with a tight 3SDCM ellipse binning for maximum color consistency.

Using thermal plastic materials with high reflection, high lifetime, and improved optical structures, the 5630 HE KK7D-ELB LED series is optimized to obtain this industry-high optical efficiency without modifying the circuit and PCB layout compared to previous versions. Thus the amount of necessary LEDs, or power used, can significantly be reduced to save energy for the whole application. For example, customers designing a 2,000 lm linear fixture using Everlight's 210-220 lm/W 5630 HE KK7D-ELB LEDs, need less than 12 watts of power consumption from the LEDs. This is a 30-40% energy saving compared to current comparable LED designs and is ideal for a broad range of professional, commercial and industrial lighting applications.

The current versions 5630 HE KK5D (195 lm/W at 5,000 K) and KK6D (205 lm/W at 5,000 K) are in mass production now. ■

## Everlight 2835 LED Package with Different Voltage Options

Everlight, a leading player in the global LED and optoelectronics industry, presents updates to its popular top view, white, low to mid power LED package in a 2835 form factor (2.8x3.5x0.7 mm) in

three voltages 3 V, 6 V, 9 V at 0.5 W and two voltages 6 V and 9 V at 1 W. Target applications are mainly for general lighting, especially consumer, commercial, and professional lighting.



**Everlight Electronics offers a popular mid-power 2835 LED package with different voltage selections for general lighting applications**

With a fabulous low dollar per lumen ratio, the 2835 package has been the most popular product among all Everlight lighting packages. It is an upgrade from standard 3528 packages. Due to a newly designed

heat slug, this LED maintains its compact size with an even lower profile and can easily be overdriven to achieve maximum flux. The 2835-ELB, an upgrade from the standard 3528, is a highly versatile package that can accommodate a wide range of wattages and voltages. Different wattage and voltage ranges are needed to optimize lamp and fixture designs to ensure best system efficiencies and cost.

**For the new 0.5 W versions, three different voltage options are available:**

3 V, 6 V, and 9 V. In addition, two 1 W high power versions are available: 6 V and 9 V. Each of these 2835-ELB LEDs excel with high efficacies, high CRI options of >80 or 90Ra, high R9 options of >0 or 50, and easy to use lambertian light patterns. 3SDCM binning is available as well to keep chromaticity coordinates under tight control. These features make the 2835-ELB package a top solution especially for general lighting applications like bulbs, linear lamps and fixtures, or downlights. ■

## Everlight Updates Shwo F-ELB LED Series

Everlight, a leading player in the global LED and optoelectronics industry, announces the Shwo F-ELB high power LED series, the latest and most powerful update to the existing high power and bright "Shwo" LED Series. Shwo F-ELB features Flip Chip technology to enable better overdrive conditions while maintaining high efficiency.



**The newest Shwo F-ELB devices are already available for sampling and mass production**

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We don't just strive to exceed expectations, we innovate to make the best of industry, perform better.

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Contact  
Lubricants

Maintenance  
& Service Aids

Everlight's Shwo F-ELB series is a high-power SMD device featuring high lumen density in a compact size and is suitable for all kinds of lighting applications including general illumination, flash, spot, signal, industrial and commercial lighting.

Everlight's Shwo F-ELB devices can be driven at 1.0 Watt with a standard operating current of 350 mA or up to 5 W with a standard operating current of 1500 mA. The luminous flux of the 1.0 W Shwo F-ELB is up to 165 lm (152 lm/W) at 6500 K CCT or 130 lm (120 lm/W) at 3,000 K CCT when driven at 350 mA of current. At 1,500 mA, the Shwo F-ELB can achieve 545 lm at 6,500 K CCT or 430 lm at 3,000 K CCT.

This high power SMD device is offered in a compact ceramic package (3.5x3.5x2.36 mm). The thermal pad of this device is electrically isolated, providing convenience in thermal and electrical design. The Shwo F-ELB series also has the advantage of a low thermal resistance of less than 5°C/W for optimized heat management. ■

## Osram Duris P 10 - Greater Luminous Flux and Thermal Benefits

A typical luminous flux of 1,100 lm from a robust, leadframe-based high-performance package and up to 50 percent lower system costs - those are the main benefits of the new Duris P 10 from Osram Opto Semiconductors. It also offers outstanding second board reliability which ensures long-term operation even in fluctuating ambient temperatures. These properties make the Duris P 10 ideal for use in professional outdoor lighting systems. It was unveiled at Light + Building 2016.



**Ideal for street lights and other professional outdoor lighting solutions: Duris P 10 - High luminous flux, robust package, low system costs**

At the heart of the new Duris are four 2 mm<sup>2</sup> UX:3 chips which are already being used in the renowned Osram LED family. Osram has opted for leadframe technology for the package which, compared with similarly sized ceramic packages, combines improved thermal properties with excellent second board reliability. This term describes the thermal interplay between the LED package and the board. If very large ceramic packages are soldered onto aluminum boards fluctuations in temperature may cause mechanical stress at the solder connections. By contrast, leadframe packages can be optimized in terms of their thermal behavior and their second board reliability.

The Duris P 10 package measures a compact 7.0 x 7.0 mm. This greatly simplifies luminaire design and reduces the space needed for the pc board and luminaire housing, which in turn means that less material is required. The high lumen value reduces the number of secondary optics needed. Together with quicker and easier handling of the luminaire in production, system costs can be reduced by up to 50%.

With Duris P 10 customers benefit from optimized heat removal through the leadframe compared with similarly sized LEDs with ceramic packages. The copper core of the leadframe ensures optimum heat removal and more efficient operation of the luminaire in the chosen application if the same cooling system is used, or savings in the cooling system for the same luminaire efficiency. "We were able to deliver these product benefits thanks to our automotive expertise", explained Dr. Ralph Bertram, System Expert at Osram Opto Semiconductors. "In developing different headlight LEDs we gained extensive experience in package technology and high-current chips. We also made use of our experience in LED mass production to develop the new Duris P 10, an extremely powerful and cost-effective product for general lighting."

All the materials for the new LED are extremely robust and are therefore ideal for outdoor applications or for use in corrosive atmospheres. The main areas of application for the Duris P 10 are street lighting, tunnel lighting, and high-bay and low-bay LED lighting systems in industrial buildings. The new Duris P 10 is available now - as is its new sister LED, the Duris P 8, with its smaller package dimensions and a luminous flux of

290 lm. In the course of the year the Duris P 9 will also be launched. This will have a luminous flux of 450 lm and will therefore be positioned in the middle of the series. ■

## Luminus' Third Gen COBs with up to 170 Lumens per Watt

Luminus, Inc., a global manufacturer of high-performance LEDs, announced a new third generation family of chip on board (COB) arrays with record-breaking efficacy and quality of light. This new product family boasts typical performance of 150 lumens per Watt efficacy in 3,000 K, 80+ CRI, T<sub>j</sub> = 85°C for use in a multitude of indoor applications and 170 lumens per Watt at 6500 K, 70CRI, 85°C for outdoor applications.



**Luminus Devices 3rd Gen XNOVA COB LEDs offer improved efficacy up to 170 lpw at 85°C**

With the third generation launch, Luminus has eclipsed their major competitors who have recently announced their own new generations of COBs with notably lower performance. These new COBs deliver up to 20 percent higher efficacy than previous second generation products by leveraging the company's latest high performance packaging technology and premium chips manufactured by Luminus' parent company, San'an. With volume production starting in May, Luminus will offer their full range of CCT and CRI combinations, including 95+ CRI Accuwhite™ and Sensus™ below black body products.

David Davito, Senior Product Marketing Director at Luminus, notes, "Our customers are delighted that we have accelerated our COB performance roadmaps to deliver industry leading efficacy which enables them to build new luminaires and retrofit bulbs with higher CRI, more flux, and lower thermal loads."

The third generation COB family is available in a wide range of popular CCT and CRI combinations, and light emitting surface diameters including 9 mm, 11 mm, 14 mm, 18 mm, 22 mm, and 27 mm. As with all Luminus COB products, the third generation line is 100 percent specified and tested at 85°C to guarantee hot performance in both indoor and outdoor applications. ■

## Seoul Semiconductor's New Acrich MJT 5630 LED with Record Efficacy

Seoul Semiconductor Co., Ltd, the world-class LED manufacturer announced that its Acrich MJT 5630D package, applicable to incandescent lamps, fluorescent lamps, and other lamps, have reached the world's best luminous efficiency of 210 lm/W, which is the highest luminous efficiency set across the world for single LED packages, and mass production has begun.



**SSC's MJT 5630D+ LED achieves the world's best luminous efficiency of 210 lm/W in its class**

Seoul Semiconductor has provided 5630 LED packages (5.6 x 3.0 mm) for the application to the lighting and IT fields and the products have been recognized as the representative mid-power LED. The currently launched MJT 5630D+ LED package's most distinctive characteristic is the upgrade of its luminous efficiency to the world's best level of 210 lm/W by using the LED chips that contain Seoul Semiconductor's multi junction technology (MJT).

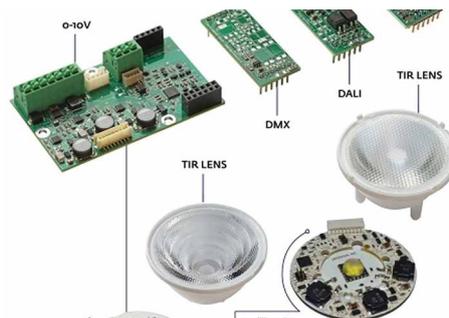
According to the SSL Plan (Solid-State-Lighting R&D Plan) released in May 2015 by the US Department of Energy (DOE), the LED is likely to take up 40% of the US lighting market that includes fluorescent lamps and halogen lamps by 2020. In addition, it forecasted that by 2030, more than 88% of the lighting equipment will be replaced by LED, thus, leading the energy saving trend.

The plan argued that, to reach its goals the luminous efficiency of the lighting application shall achieve at least 200 lm/W and the luminous efficiency of LED packages shall be at least 220 lm/W. In addition, it suggested a strategy for improving the performance of converters that has lowered the efficiency and life of current LED lamps and a strategy for expanding the AC LEDs and high-voltage LEDs as ways to improve the efficiency of LED lighting application. SSC's Acrich driving technology and Acrich MJT technology are in compliance with the AC and high voltage technologies described in the report released by the US DOE. Seoul Semiconductor plans to expand the supply of Acrich MJT, thus, opening the era of high efficiency and long lasting LEDs.

Mr. Ki-bum Nam, CTO of Seoul Semiconductor, said, "The Acrich driving technology and Acrich MJT technology emphasized by the US DOE are the next generation LED technologies which would lead the future LED market". He added that, "We will further prove our distinctive technology by achieving the luminous efficiency of LED package of 220 lm/W within a year, the US DOE's target achievement by 2020." ■

## Bluetooth Mesh-Controlled Light Engine

At LIGHTFAIR International (LFI 2016), LED Engin, Inc. demonstrated its LuxiTune™ linear dynamic light engine - the world's first Bluetooth® low energy (BLE) mesh-controlled tuneable white solution for linear luminaires. Adding a comprehensive BLE interface enables end users to wirelessly configure, control and manage linear luminaires to produce dynamic, coherent and fully tuneable lighting schemes seamlessly.



**LuxiTune from LED Engin is now available with integrated Bluetooth® low energy (BLE) for a mesh-controlled tuneable white solution**

Installed in a 4 x 4 x 48 inch fixture such as a slot or pendant, the linear light engine delivers 650 lm/ft out of the diffuser. At full intensity, CRI is over 90 at 3,000 K and colour uniformity is three MacAdams or better over the module length. Dimming is smooth, flicker free and goes down to 3%. As well as enabling control via a BLE mesh network, the LuxiTune™ linear light engine also interfaces seamlessly with third party 0-10 V, Dali, DMX and Zigbee controllers.

By employing the latest BLE mesh protocol, the module ensures the security that large commercial applications demand if they are to be controlled from smart devices. BLE provides multi-level secure access to both the control system and mesh network.

President and CEO of LED Engin, David Tahmassebi, commented, "While tuneable LED modules for directional lighting may have addressed the challenges of making tuneable light appear more natural, uniform and vibrant, linear light fixtures still face hurdles in achieving an enhanced tuneable solution. LuxiTune's linear dynamic light engine delivers precise colour control and unrivalled uniformity across the module length."

LED Engin also demonstrated its LZP RGBW and LZ7 emitters, which are particularly suited to architectural lighting, accent lighting and effect lighting. Its LZP RGBW MCPCB with connector has the exact same form factor as LZP LuxiTune™ MCPCB and therefore a tuneable white fixture may be converted to an accent lighting fixture by simply using the LZP RGBW board. ■

## New Lumileds Matrix Platform for Simplified Indoor Fixture Design

Lumileds introduced the Luxeon XR-3020, an ultra-slim module that serves as a building block for TLEDs or thin office and industrial fixtures. These slim (20 mm) products are available with 24 LEDs on a 280 mm thermally-conductive board or 48 LEDs on a 560 mm board. The modules provide 1,100 or 2,200 lm, respectively, at 160 lm/W and 100 mA drive current per LED, with a board temperature of 45°C. Luxeon XR-3020 is the latest addition to the Matrix Platform family of infinitely configurable LED boards, linear flex strips and modules utilizing the industry's most dependable LEDs.



**Lumileds' Luxeon XR-3020 is an efficient, reliable, and ultra-slim module that accelerates the design of indoor area lighting applications**

"Common indoor area lighting applications such as troffers or TLEDs benefit from drop-in solutions that enable rapid luminaire assembly," said Andrew Cohen, Product Manager of Lumileds Matrix Platform. The turnkey nature of Luxeon XR-3020 minimizes time to market and simplifies the supply chain by reducing optical and mechanical design efforts. The Luxeon 3020 LEDs used on the modules can be driven at a maximum drive current of 240 mA, the highest in the industry for mid power LEDs, and have passed 50,000 hours of LM-80 testing. The modules also have a five year warranty.

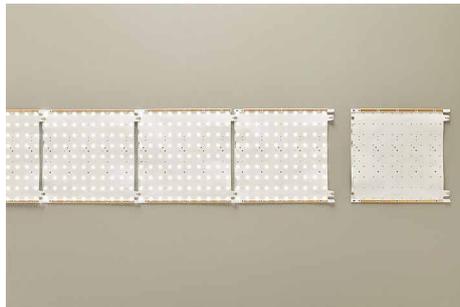
The Luxeon XR-3020 is available in 3,000 K to 5,000 K at 80 CRI and at 4,000 K at 90 CRI. Up to 10 of the 280 mm modules can be connected in series or 16 modules connected in parallel, utilizing the four poke-in connectors per board (driven at 200 mA). For the 560 mm modules, up to 10 modules can be connected in series or 8 modules connected in parallel (driven at 400 mA). Each board is also capable of high current operation (480/960 mA respectively). The Luxeon XR-3020 module uses a Super CEM3 PCB (composite epoxy material), enabling superior mechanical robustness and maximum heat dissipation.

Lumileds Matrix Platform includes off-the-shelf and built-to-spec options, enabling a virtually limitless range of solutions for any lighting application. ■

## Cooledge Brings Color Tuning from 2700 K to 5700 K to TILE Series

Cooledge introduced their color tunable TILE products at the Light + Building exhibition mid March in Frankfurt Germany.

Color temperature control allows architects and designers to make light feel more natural and to create drama in retail, and hospitality environments. Interior 'skylight' lighting can change through the day, replicating the behavior of sunlight. Walls and ceilings too can be tuned to create an emotional response in hospitality, retail and entertainment environments.



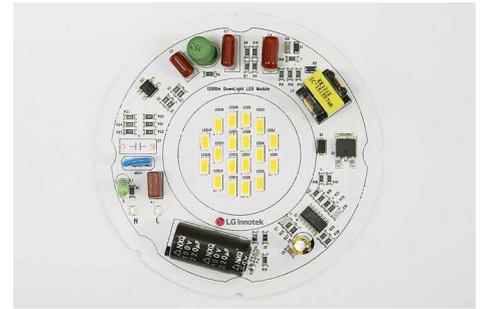
**The Cooledge TILEs will be offered with a color tuning option from 2,700 K to 5,700 K very soon**

"The ability to reproduce natural lighting conditions is of great importance to architects and lighting designers," said Philippe Schick, Vice President of Product Management at Cooledge. "As we see more 'interior skylights' being designed into retail and hospitality environments, it's clear there's a growing need for luminous surfaces to mimic the quality of light we get from the sun. The ability to control color as well as light output has become essential."

Cooledge has expanded its portfolio into four ranges, Ceiling, Wall, Display and Perimeter more closely representing where its TILE and LINE products are incorporated. "Illumination needs and installation requirements vary by environment and desired effect," said Schick. "Our new ranges recognize those differences and offer more tailored solutions to simplify the selection and specification process." ■

## LG Innotek Develops Driver on Board LED Module For Lighting

LG Innotek announced that the company succeeded in developing a DOB (Driver on Board) LED module whose convenience and performance have sharply improved. The DOB LED module integrated the switched mode power supply (SMPS) on its board. So you can simply use this module for indoor lighting. Further, it can implement the function of dimming, and even reduce flicker.



**LG Innotek's new 9 W DOB LED module is an alternative to so-called AC direct modules**

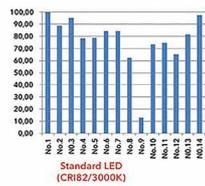
The early stage of AC Direct modules integrated a current-controlling driver IC in the module which controls the current and voltage, but it has difficulty with detailed and stable power source management. The DOB LED module has very low flicker. Flicker percent is 20% or less at all dimming ranges, which is about 60% lower than the AC Direct module. This product also provides efficacy of 140 lm/W, the best performance in the 9 W category (CRI is above 80), which is 30% higher than the AC Direct module.

The LED industry believed that, if the SMPS is integrated into the LED module, the heat from the LED chip and the SMPS would be transferred to the whole module, reducing the stability and efficiency of the lighting and decreasing its lifespan. LG Innotek, however, developed its proprietary circuit design and heat-sink design to improve product performance and lifespan. Its lifespan has also increased up to 50,000 hours. ■

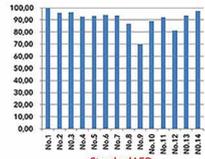
## Verbatim's Vx-Filter Technology Enriches Lighting Spectrum

Using proprietary technology from its parent company, Mitsubishi Chemical, Verbatim introduces an innovative filter designed for use with its track lights, and GU10 and MR16 lamps to simultaneously boost the color rendering index (CRI) and vividness of colors perceived. The Vx-filter delivers precise changes to the spectral distribution curve of existing LED products to ensure that colors and finer details of objects appear as they would be perceived in natural daylight. This improvement in color fidelity and vividness is a solution that is particularly useful for retailers, museums and hospitality venues where small differences in color hues, tints and textures can have a significant impact.

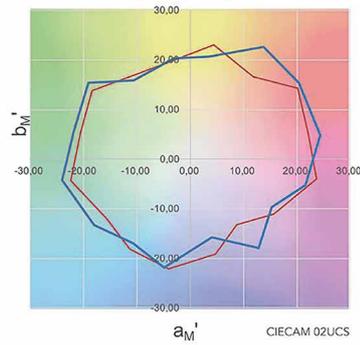
## Vx-filter CRI comparison



Ra=82

Standard LED (CRI82/3000K) with Vx-filter  
Ra=94

## Color Space Comparison



Standard LED (CRI82/3000K) Rf = 81 Rg = 95

Standard LED (CRI82/3000K) with Vx-filter Rf = 90 Rg = 101

**Vx-filter technology allows customers to tune Verbatim's products to meet requirements at a later stage**

Vx-filter technology allows Verbatim customers the versatility to buy products for an installation knowing that they can be tuned to meet requirements at a later stage. Usually, customers must decide between selecting high efficacy or high CRI retrofit LED products but this new accessory can make both options available.

Made from a bio-based engineering plastic called DURABIO™ developed by Mitsubishi Chemical, the Vx-filter has excellent optical properties such as high transparency and superb light transmission. With an exceptional lifetime of 50,000 hours, the accessory also features high heat and excellent scratch and UV resistance.

"Filters usually filter out something that is unwanted. The Vx-filter technology developed by Mitsubishi Chemical for Verbatim's GU10, MR16 and track lighting products, 'filter in' light that is desired to provide colors being perceived as they would appear under natural daylight," explains Dick C. Hoogerdiijk, General Manager LED EUMEA, Verbatim. He adds: "Although CRI is increased by the use of Vx-filters, this is not the measurement that is relevant for this type of specialist solution. It is more important to consider the unique characteristics of the light that are adjusted to make objects appear more vivid with high perception fidelity." ■

## Dimming Interface IC Delivers up to 70% Reduction in Component Count

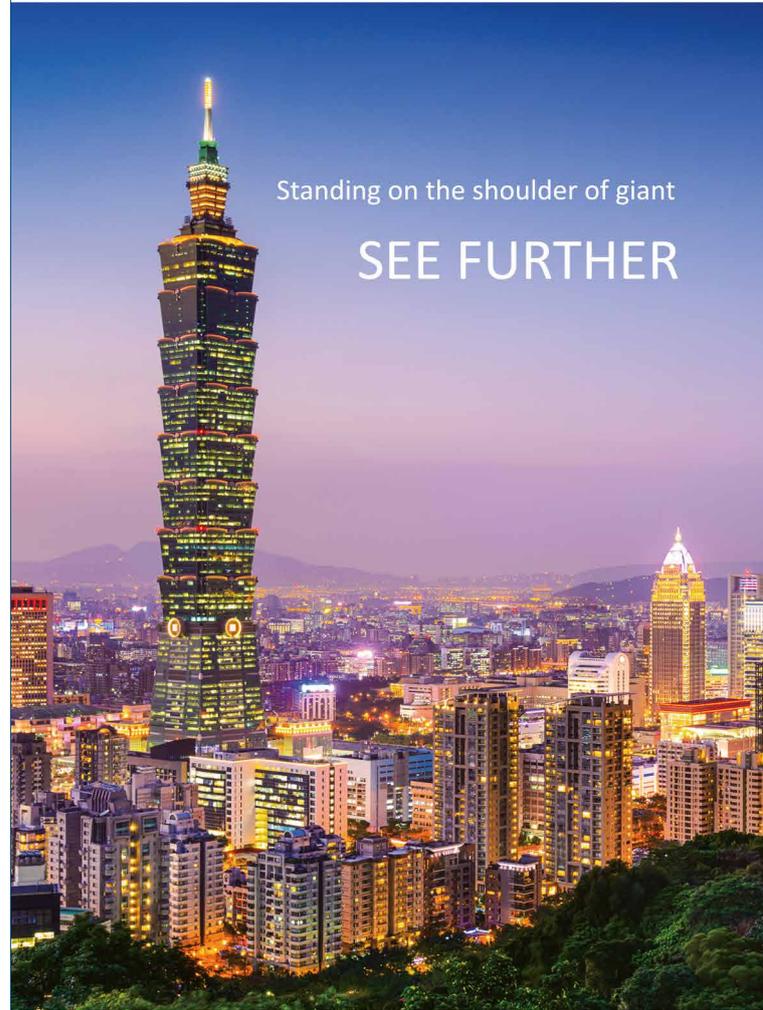
Infineon Technologies launched the CDM10V. The compact and highly integrated LED lighting interface IC allows designers to replace many of the discrete components used in conventional dimming schemes with a single device. Thus, it can reduce the component count and PCB space needed for dimming circuitry in LED lighting applications by up to 70 percent.

Infineon's CDM10V is the industry's first single-chip lighting interface IC capable of transforming an analog 0-10 V input into a PWM or dimming input signal required by a lighting controller IC. The signal is delivered as 5 mA optocoupler-ready PWM signal with 0 to 100 percent duty cycle.

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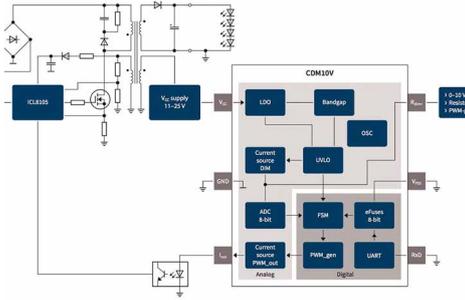
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Typical application schematic using CDM10V

The CDM10V can be used across a variety of different commercial and industrial LED lighting applications. This is enabled by one-time configuration of key parameters such as minimum duty cycle (1 to 10%), PWM output frequency (200 Hz to 2 kHz), dimmer/resistor bias current (50  $\mu$ A to 500  $\mu$ A) and 'dim-to-off' functionality. Furthermore, with 'dim-to-off' enabled the IC also provides the option of accepting PWM input signals.

Supplied in an ultra-miniature 6-pin SOT package, the CDM10V is ideally suited for use on small PCBs with high component densities. A supply voltage of 11 V to 25 V ensures compatibility with all common LED lighting applications including luminaires, troffers, downlights, sconces, office lighting and signage.

#### Summary of Features:

- Minimum duty cycle: 1%, 2%, 5%, 10%
- PWM output frequency: 200 Hz, 500 Hz, 1 kHz, 2 kHz
- Dimmer/Resistor Bias Current: 50  $\mu$ A, 100  $\mu$ A, 200  $\mu$ A, 500  $\mu$ A
- Dim-to-Off: disabled/enabled

#### Benefits:

- Programmable
- Wide input Vcc range from 11 - 25 V
- Transparent PWM mode
- Replaces many external components with single chip reducing BOM and PCB space
- Minimum variation from device to device

#### Target Applications:

- LED Drivers needing 0 - 10 V Dimming Circuits
- Luminaires
- Troffers
- Downlights
- Sconces
- Undercabinet
- Office Lighting
- Signage applications

The CDM10V joins a comprehensive portfolio of Infineon devices - including driver ICs and MOSFETs designed to simplify and speed the design of LED lighting applications. ■

## Diodes Triac-Dimmable LED Driver with Excellent Dimmer Compatibility

Diodes Inc's new AL1697 LED driver targets line-powered, triac-dimmable LED lighting applications. This device provides compatibility with leading and trailing edge triac dimmers using a single-stage, high power-factor dimming circuit that complies with the NEMA SSL-6 dimming curve, delivering optimal line and load regulation. This integrated MOSFET eliminates the need for an auxiliary winding, which lowers BOM cost and enables a smaller PCB, making this an attractive and competitive solution for driving LED lamps up to 15 W.



Diodes' latest triac-dimmable LED driver, AL1697, is designed to provide excellent dimmer compatibility for both 230 VAC and 120 VAC replacement lamps

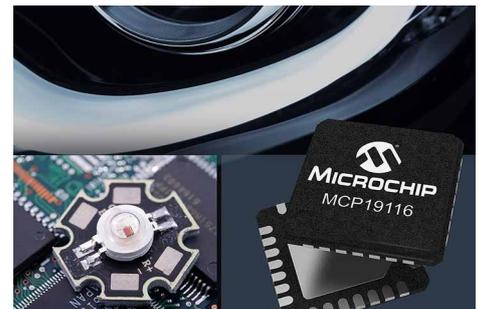
The AL1697 is a high-precision, high-efficiency, buck-boost LED driver whose topology provides an accurate output current that enables exceptional line and load regulation. This design supports non-isolated (buck-boost) operation to address the isolation requirements for different lamps. Operating in boundary-conduction mode achieves higher conversion efficiency while also reducing switching noise and eases EMI design. The device features a low, 130  $\mu$ A startup current and a low operating current of 170  $\mu$ A.

The MOSFET options provide a drain-source, on-resistance specification of 4  $\Omega$  for operation up to 2 A at 600 V, or a super-junction RDS(ON) of 1.8  $\Omega$  that can support 4 A at 650 V. The AL1697 offers standard

internal protection features, such as output short-circuit, over-temperature, under-voltage lockout, leading-edge blanking and cycle-by-cycle over-current protection. The device also features over-voltage/output-open and thermal foldback protection for enhanced safety and reliability. ■

## Microchip New Digitally Enhanced Analog LED Power Controllers

Microchip announces two new digitally enhanced power analogue controllers designed for LED lighting applications. The MCP19116 and MCP19117 increase accuracy for LED lighting and allow users to carefully control LED light output levels without sacrificing colour or light quality for reliable long-life applications.



Microchip's MCP19116 and MCP19117 enable intelligent, configurable, and accurate LED lighting

#### Key Features:

- MCP19116 and MCP19117 enable intelligent, configurable, and accurate LED lighting
- Integrates an intelligent PWM controller with a PIC<sup>®</sup> MCU core
- Combines cost savings with reliability, efficiency, and light quality
- Digital interface supports communication and configuration and remote monitoring/control

Efficiency and longevity have consistently been drivers in LED adoption. However, light quality remains one of the most important system considerations. Colour, brightness, and controllability are the key to a successful lighting product. By combining the power and performance of an analogue-based controller with the flexibility of a digital interface, the MCP19116/7 is an intelligent pulse width modulation (PWM) controller with a fully integrated PIC<sup>®</sup> MCU core that can deliver

cost savings while still providing the highest standards in reliability, efficiency, and light quality. The digital interface also allows for communication and configuration, allowing a subsystem to report status or be remotely controlled. This functionality is necessary for adding lighting to many applications, especially high-reliability automotive and remotely accessible internet of things (IoT) devices.

The LED lighting industry continues to grow in market share and reach. A report from Big Market Research from 2015 indicated strong market growth for LED lighting, anticipating the industry to grow 45 percent per year through to 2020. The market is also expected to reach over \$63 billion in 2020. These predictions are consistent throughout industry analysts.

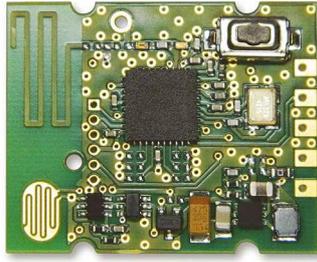
Microchip also announces the MCP19117 Flyback Evaluation Board (ADM00663), priced at \$49.99, which is available now. This evaluation board is offered with a flyback design supporting constant current loads up to 50 V, perfect for driving a medium-voltage LED string.

Also available for the MCP19116 and MCP19117 is Microchip's full suite of development tool support including MPLAB® X Integrated Development Environment (IDE). An MPLAB X plug-in specific to the digitally enhanced power analogue controllers is also available.

The MCP19116 is in a 4 x 4 QFN package, and the MCP19117 in a 5 x 5 QFN package. Both devices are available now for sample and volume production. ■

## EnOcean Announces New 2.4 GHz Portfolio

At Light + Building 2016, EnOcean presented a new self-powered product family for wireless communication in the globally usable 2.4 GHz frequency band. This adds to the company's products in 868 MHz, 902 MHz and 928 MHz for new markets and regions. With the 2.4 GHz offering, OEMs can now realise batteryless switch applications for worldwide use. This development emphasises EnOcean's know-how in kinetic energy harvesting based on the field-proven electromechanical energy converter ECO 200.



**The PTM 535Z is one out of three products from EnOcean's new 2.4 GHz product family**

**The EnOcean 2.4 GHz product family includes:**

- PTM 215ZE - a 2.4 GHz radio pushbutton transmitter module. It is mechanically compatible with the industry standard PTM 21x module form factor (sub-1 GHz) to ensure an easy integration into a wide range of switch designs, allowing efficient migration paths
- PTM 535Z - this 2.4 GHz radio transmitter module, combined with the ECO 200 energy converter, has a smaller form factor than the PTM 215ZE and is suitable for custom switch designs in industrial, consumer and Internet of Things (IoT) applications. 3D data, provided together with the technical data sheet, facilitates the prototyping of various housings
- TCM 515Z - the 2.4 GHz radio transceiver with ESP3 interface enables quick integration of EnOcean 2.4 GHz solutions into actuators, gateways and controllers

The new 2.4 GHz portfolio enables integration of EnOcean's technology into 2.4 GHz systems, such as ZigBee. It opens the self-powered technology to new markets, particularly for applications that request a global use for energy harvesting wireless communication.

Thus, manufacturers of 2.4 GHz based products can now integrate EnOcean energy harvesting in their portfolio for batteryless, wireless room-level control. Due to the EnOcean standard form factors, OEMs can easily use the new 2.4 GHz modules to develop various kinetic-powered applications such as wall switches, contact sensors or remote controls.

"With 2.4 GHz, we complement our portfolio in sub-1 GHz for building automation and smart home with a worldwide frequency that addresses the desire of global players to employ self-powered wireless sensors for

different Internet of Things applications," says Dr. Wald Siskens, CEO of EnOcean. "It also proves that the capabilities of our kinetic energy harvesting technology can run any kind of ultra-low power radio."

**Energy for the self-powered Internet of Things:**

EnOcean uses the principle of energy harvesting for its wireless sensor solutions. The technology's secret ingredients are miniaturised energy converters, which convert kinetic, solar or thermal energy into electrical power. Together with an efficient energy management system, this platform enables self-powered IoT devices to communicate on various radio standards - without installing complicated cabling or fitting batteries - for use in building automation, smart home, LED lighting control as well as for industrial applications. ■

## Power Integrations' New LYTSwitch-3 LED Drivers

Power Integrations (Nasdaq: POWI), the leader in high-efficiency, high-reliability LED driver ICs, announced the LYTSwitch™-3 family - the latest addition to the company's LYTSwitch line of LED driver ICs. Ideal for bulbs, tubes and downlights up to 20 watts, LYTSwitch-3 ICs offer excellent dimming performance with both leading-edge and trailing-edge TRIAC dimmers, and support both isolated and non-isolated topologies.



**The new LYTSwitch-3 LED Driver ICs suit both non-isolated lamp designs and isolated ballast topologies**

LYTSwitch-3 ICs feature programmable dimming profiles, enabling designers to optimize drivers for dimming range and efficiency. Deep dimming response is also programmable - to extend dimming range or engage the load-shutdown mode to eliminate the possibility of shimmer. When no dimmer

is connected or the dimmer is set at full conduction angle, the IC's dimmer management circuitry is turned off, improving efficiency. Uniquely, the new driver continuously manages power factor, even in dimming mode, which minimizes apparent power draw (VA) as the bulb dims, preventing power quality excursions in large installations. LYTSwitch-3 ICs also include a thermal-foldback feature that automatically dims the light output to compensate for inadequate fixture cooling or high ambient temperatures, preventing damage and increasing lamp lifetime.

Hubertus Notohamiprodjo, product marketing director at Power Integrations explained: "These new driver ICs can be used to provide buck, boost, buck-boost, tapped-buck, tapped-buck-boost and isolated flyback topologies. They are compatible with the widest range of dimmers and provide a choice of MOSFET breakdown voltages for optimized designs. This means that multiple single-sided, ultra-small designs can be based around one IC, reducing design cycle time and part inventory."

Featuring a power factor of greater than 0.9 and THD of less than 10%, LYTSwitch-3 driver ICs meet all international efficiency standards including EN61000-3-2, CEC Title 20, CEC Title 24 and ENERGY STAR®. The ICs also provide 3% constant-current (CC) accuracy over load, line and from device to device. Like all Power Integrations products, the highly integrated devices include comprehensive protection features while requiring fewer external components than competing discrete designs, enhancing reliability while reducing BOM costs and PCB footprint. ■

## Dialog Semiconductor - New Flickerless™ High Power Drivers

Dialog Semiconductor plc, a provider of highly integrated power management, AC/DC power conversion, solid state lighting (SSL) and Bluetooth® Smart technology, announced two new driver controllers for high power commercial LED lighting applications up to 90 W. In these applications flicker-free operation is essential to avoid eye stress, particularly where there is long-term exposure to the light source. Dialog's patented Flickerless™ technology

virtually eliminates flicker through digital control that achieves near-zero line frequency ripple.



**Highly integrated, two-stage LED drivers deliver flicker-free performance, simplified designs with low bill of materials; dimmable version offers smooth dimming down to 1%**

The iW3629 (non-dimmable) and iW3631 (dimmable) digital power controllers simplify the design of LED power supplies by replacing up to 45 discrete components. Both devices can be used with small input and output bulk capacitors, and small transformers. This cuts power supply size, bill of materials and costs while optimising performance. The controllers feature better than 0.95 power factor (PF), less than 15% total harmonic distortion (THD) and 85%+ efficiency over a wide load range, easily meeting the requirements of the Design Lights Consortium (DLC)1.

The controllers comprise a two-stage design with a rectified AC-input (90 to 277 VAC), active start-up, and a boost circuit feeding a flyback converter. The latter provides a constant current drive to the LEDs. Quasi-resonant control in both stages maximizes power efficiency. Dialog's PrimAccurate™ primary side sensing technology produces tight line and load regulation while eliminating the need for secondary side feedback components. Fast, smooth start-up takes less than half a second and PF settling time is minimal.

The iW3631 dimmable controller has a flicker- and shimmer-free dimming range of 1% to 100%. It has a built-in interface to industry-standard, 0-10 V analog dimmers, so there's no need for an external driving source or microcontroller, and a dimming interface to support wireless solid state lighting applications.

Davin Lee, Senior Vice President and General Manager of the Power Conversion Business Group at Dialog Semiconductor,

said, "Commercial LED lighting customers are the most demanding in terms of LED lighting performance and reliability. However, the market is just as price sensitive as the consumer sector so we are constantly striving to help customers create lighting that combines leading-edge performance with the lowest possible cost. These two new high power LED driver controllers do exactly that, using proven, patented technologies that produce visible competitive edge." ■

## Samsung Introduces Smart Lighting Module for IoT Lighting

Samsung Electronics introduced a multi-purpose Smart Lighting Module (SLM) - the most fundamental IoT building block - for the fast-growing, smart building and smart city markets. By providing the core building block for a wide variety of potential smart lighting systems, Samsung's SLM will play a key role in speeding up system development, lowering risk, improving system quality and reducing time to market for smart lighting manufacturers. The module will be sampled with Samsung smart lighting partners and will be shipped to OEMs in April.



### Samsung's Smart Lighting Module (SLM)

"After announcing our smart lighting platform concept last year, we are now rolling out what can be considered the most critical component in a smart lighting system," said Dr. Jacob Tarn, Executive Vice President, LED Business Team, Samsung Electronics. "Our SLM solves many of the problems that OEMs are finding in today's smart building and smart city IoT applications."

Samsung's SLM is at the heart of the Samsung Smart Lighting Platform, which is designed for integration with LED lighting systems in order to easily transform luminaires into smart, digital nodes. This Internet of Things (IoT) platform incorporates

processing capabilities, firmware, connectivity and an open architecture connected to sensors for collecting data and creating new applications.

As the core element of the Smart Lighting Platform, the SLM serves as the essential connector for all types of devices used in smart luminaires including sensors and drivers. The new smart lighting module offers several ports for greater flexibility in making hardware connections, and a script engine that simplifies firmware connections. These allow OEMs to customize a smart lighting device to their needs much faster, permitting development time to be 50 percent shorter or even better with the SLM than without it.

The new Smart Lighting Module also features wireless software update functionality (OTA) and power metering. The SLM enables most smart devices to talk to one another by supporting all open wired and wireless communication protocols, utilizing not only Zigbee or DALI, but also the Bluetooth protocol. It seamlessly connects to most

sensor networks and effectively interacts with smart control devices such as mobile phones. This enables smart luminaires to serve as the nodes within a wide variety of smart lighting environments.

Samsung SLM comes in three different types, SLM-D, SLM-A and SLM-P. The SLM-D uses DC input voltage of approximately 12 V to 24 V from AUX power, while the SLM-A has full functionality with AC voltage from 120 V to 277 V, and the SLM-P is an upgraded version of SLM-A, which adds a power metering function.

Samsung said that it will reinforce its SLM as a leading end-to-end connectivity solution by forming partnerships with providers of smart components, LED drivers, sensors and gateways to cloud and analytics solutions. Already, Samsung has formed key partnerships with Daintree for indoor applications, Silver Spring Networks for outdoor applications and FLIR for thermal image applications. ■

## TRP Introduces New High Performance T5 LED Driver

Thomas Research Products has introduced a new high performance 75 W LED driver with a long form factor matching T5 fluorescent ballasts. Dimming capabilities (0-10 V) works with controls and sensors to maximize energy savings. Thomas Research Products manufactures SSL power and control solutions.



TRP's LED75WT5 driver series has a long form factor matching T5 fluorescent ballasts

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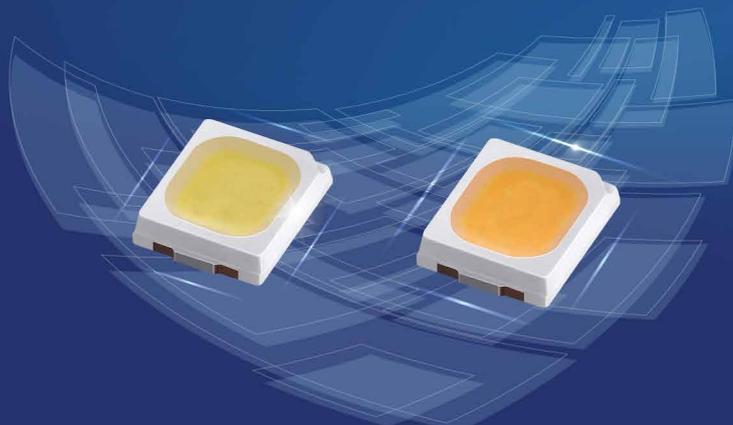
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### Popular Mid-power 2835-PCT with Different Voltage Selections for LED Bulb Application



130  
lm/W

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LM-80

#### 2835 Features

- Available in 3V, 6V, 9V, 18V, 24V, 36V
- High Efficiency, up to 130lm/W
- Excellent color, 3-step MacAdam ellipse
- High air tightness, New Process PCT 2835, Good Anti-oxidation capacity
- Long Life Span, 9000hrs LM-80 certified

## NEW! New AC Technology replaces powersupplies for LED!



This new technology replaces conventional powersupplies by working with out capacitors, inductures, transformers and all components, which have limited lifetime. By newest IC technology the complete drivers can be placed on a LED module for direct connection to 230 VAC.

This increases dramatically the reliability and lifetime! It saves space, reduces weight and is dimmable (symmetrical illumination). Modules from 3 Watt (30 mm dia) up to 40 W (54 mm dia) are standard products and samples ex works are available!

» Also custom designes are available on request

- » The driver circuit includes a fuse, varistor and NTC for internal temperature control (max + 85°C)
- » The modules can be operated in AC and DC!
- » CRI > 80, CCT 2700 K up to 5800 K
- » PF > 98, connecting to DALI is possible, THD > 20%
- » Isolation proof > 3 kV on IEC 61347, IEC 60598, IEC 60204
- » Expected Lifetime > 50.000 h
- » EMI tested
- » Working temperature -40 ... + 85°C, Totally free of flickering
- » TÜV certified

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NEWS

PRODUCTS

The LED75WT5 driver series is derived from TRP's current high performance drivers, redesigned with a narrow cross-section to fit T5-style ballast channels. This flexibility allows OEMs to utilize the driver in new low profile luminaire designs or for LED retrofits in the field. The UL Type TL certified driver features universal 100-277 V input and flicker-free output.

TRP's new driver features the same high performance for which the company's other drivers are known. Available in constant current, dimmable and constant voltage versions. The driver is rated for indoor use in dry and damp locations. It comes with the company's standard 5 year warranty.

All LED Drivers from TRP offer high quality, long life, high efficiency and are cost-competitive. Information is available on the company's website. Availability of the LED75WT5 series begins 2Q2016. ■

## Onetrack: Only One Track for All Your Lighting Ideas

In launching the new track lighting components range, named ONETRACK®, the company made a very precise choice in positioning and differentiating from other players; producing only one type of track that combines the functionalities of all the current systems in the market. This means a switch from generally defined "EUROSTANDARD" tracks to "EUROSTANDARD PLUS®" tracks. The reason why they made this decision is the strong belief that this kind of track, and the concept on which it is based, can become a new shared standard and bring great advantages to all the players in the production chain.

EUROSTANDARD PLUS® tracks are 6 conductor tracks that make the upgrade to controllable lighting systems possible at any time. This state-of-the-art platform makes ONETRACK® the best solution for controllable lighting. This makes the system suitable to be used in Human Centric Lighting systems that are the future of biologically efficient lighting.



The ONETRACK System from A.A.G Stucchi provides 6 conductor tracks and aims to be a one-for-all solution, making any other track system obsolete

## Mold Silicones (and other things) in a Snap.

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EUROSTANDARD PLUS® tracks are a universal platform that fit any current and future need and guarantee the freedom to choose the lighting system for your project at any time. This means flexibility for lighting projects.

One of the big advantages of this system is that it can be integrated with wireless lighting control management systems by simply inserting the specific adapter into the track. The track itself then carries the signal to all the lighting fixtures on it, without any wiring.

ONETRACK® can be integrated with different wireless control systems providing countless lighting scenarios and energy management solutions.

Moreover, the company has developed new components together with some clients as Regiolux for the new H profile track that allows the creation of indirect light or Targetti for the new concealed adapter with integrated driver that meets the requirement for miniaturization of components in lighting applications.

But that's not all! A.A.G. Stucchi has decided to "go further" with the development of the track lighting components range and think about something that could really be new for its customers. The new line of modules to create linear light with a track or an extruded profile as a base is on its way. The core of the project is, of course, a particular adapter that allows you to use the different modules on the track easily and without interruptions in light. ■

## WEBINARS



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瑞豐光電

# RGB SMD LEDs

Since the foundation of 2000, Shenzhen Refond Optoelectronics Co., Ltd (REFOND) listed in 2011 July (Stock Code: 300241). REFOND is one of the biggest LED manufacturers in China, it is positioning in the high-end customers worldwide to provide high-quality LED light source.

Refond's RGB SMD LED has an IPX6 grade of waterproof with high contrast, light type consistency, high reliability. It also be widely application for outdoor full-Color LED screen display, decorative lighting and other electronic devices.



**3535**  
outdoor series



**2727**  
outdoor series



**2321**  
outdoor series

## Features

- ◎ All RGB SMD product include "surface black type" and "all black type"
- ◎ Matte surface
- ◎ Water-resistant (IPX6)
- ◎ Moisture sensitivity level: 5a
- ◎ Pb-free reflow soldering application
- ◎ RoHS compliant
- ◎ High luminous Intensity, Low power dissipation, Good reliability and Long life



SHENZHEN REFOND OPTOELECTRONICS CO.,LTD.

Add: Building #1, 10th Industrial Zone, Tian Liao Community, Gong Ming Area,  
Guang Ming New District, SHENZHEN, CHINA

Sales: Mr. Jay Lee Mobile No: +86-138 2888 4001 E-mail: xiaojie.li@refond.com

Stock Code : 300241.SZ  
[www.refond.com](http://www.refond.com)



## TECHNICAL REGULATORY COMPLIANCE UPDATE



Segment	Product	Standard (Certification)	Region	Technical Regulatory Compliance Information
Lighting	Luminaires	SASO IEC 62722-2-1/2015	Saudi Arabia	<p>IEC 62722 applies to luminaires for general lighting purposes. It specifies the performance requirements for LED luminaires, the testing methods and conditions, required to show compliance with this standard. The following types of LED luminaires are distinguished.</p> <ul style="list-style-type: none"> <li>• Type A - Luminaires that use LED modules where compliance with IEC 627171 has been proven.</li> <li>• Type B - Luminaires that use LED modules where compliance with IEC 627171 has not been proven.</li> <li>• Type C - Luminaires that use a LED lamp and covered in IEC 62722-1</li> </ul> <p>These requirements only relate to type testing and it does not cover Type C luminaires or LED luminaires that intentionally produce coloured light. It comes into force on April 19<sup>th</sup> 2016</p>
Electrical and Electronics	Electrical and Electronics	RoHs 2	China	<p>China RoHS 2 covers electrical and electronic products, which are dependent on electric current or electromagnetic fields to work, or to generate or transmit current which are designed for use with a voltage rating not exceeding 1,000 Volt for alternating current and 1500 Volt for direct current. The standard does not contain a list of specific products hence making the a wider scope affecting following chemicals:</p> <ol style="list-style-type: none"> <li>1. Lead and its compounds</li> <li>2. Mercury and its compounds</li> <li>3. Cadmium and its compounds</li> <li>4. Hexavalent chromium compounds</li> <li>5. Polybrominated biphenyls (PBB)</li> <li>6. Polybrominated diphenyl ethers (PBDE)</li> </ol>
Lighting	LED Lamp	AS 4777.2:2015	Australia	<p>As per the new AS 4777.2:2015 standard, all PV Inverter certificates must be updated by 9 October 2016. The RCM mark can be placed on a product on the basis of an SAA certificate, provided that the other conditions of AS/NZS 4417.2 are followed. The importer must complete all those conditions. It is illegal for overseas companies to use a local agent to register for RCM on their behalf. Please note that the use of the RCM for electrical safety is not mandatory and has not been legislated in Victoria or New South Wales. It is possible to register for the RCM for EMC only, as the RCM will be replacing the C-tick this year in March. It is suggested that importers should check with their electrical safety regulators in their State for the requirements. Amendment 3 of AS/NZS 60335.1:2011 has been released which becomes mandatory on 30 November 2017</p>
Lighting	LED Lamps with Integrated Control Bases	Administrative Rule No. 144, 2015	Brazil	<p>On 24 February 2016 the Brazilian National Institute of Metrology, Quality and Technology (INMETRO) published Administrative Rule No. 76, 2016, to make adjustments to the conformity assessment program for LED lamps with Integrated Control Base.</p> <p>From 17 February 2016, LED lamps with integrated control bases should be manufactured and imported only in accordance with the requirements approved herein and duly registered in INMETRO.</p> <p>It is in force since Feb 26, 2016</p>
Lighting	Lamps	EnergyStar Lamps 2.0 - Memo February 2016	Worldwide	<p>EPA published on 11. February 2016 a memo to the specification Lamps 2.0. It clarifies the handling of:</p> <ul style="list-style-type: none"> <li>• Handling of R9 requirement</li> <li>• Reporting of Spectral Power Distribution</li> <li>• CFL lumen maintenance reporting</li> <li>• Lumen maintenance supplemental guidance</li> <li>• Lamp packaging CCT descriptors</li> </ul> <p>Note that EPA will provide a updated version of Lamps 2.0 at end of February.</p>
Lighting	Luminaires and Lamps	EPA TM-21 and TM-28	Worldwide	<p>EPA published new TM-21 and TM-28 calculation tools on 9 February 2016 to be used for all Luminaries and Lamps specification as applicable. The TM-21 calculator was updated to include also the ideas of the Addendum-A of TM-21-11</p>

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## How the Continued Growth of the LED Lighting Market Depends On Intellectual Property, Collaboration and Innovation



*The strength of the Dow Corning's IP portfolio has become increasingly critical to continued innovation along the entire value chain.*

Only two decades ago, investing the resources to develop LEDs into an alternative light source required a greater risk than any single company could take on alone. Collaboration was critical to the industry's infancy. Sharing basic research and innovations not only helped accelerate and enhance early-stage research, it also distributed the inherent risks among several players.

This was particularly true for Dow Corning, when it began its research and development of silicone LED encapsulants two decades ago. Already a recognized collaborative pioneer in such diverse industries as automotive, healthcare and semiconductor manufacturing, Dow Corning understood the power of shared innovation with its customers. In fact, the company's active dialogues with optoelectronics customers is what alerted it to the fast-emerging LED lighting industry, and the potential ways that silicone could improve the reliability and lifetime of solid-state lighting designs.

Early LED lighting relied on epoxy and acrylic encapsulants to perform two critical functions. They served to protect the sensitive light emitting diode from moisture and dirt, and helped shape and focus the light. But as LED dies grew in power and density, Dow Corning recognized conventional organic materials would not withstand the higher heat and lumens. Specialty silicone encapsulants, in contrast, offered much higher photothermal stability and ensured greater performance and reliability. Dow Corning further recognized that neither it nor LED manufacturers could optimize silicone materials without working

together. Thus began Dow Corning's close innovation with LED industry pioneers.

### How the Continued Growth of the LED Lighting Market Depends On Intellectual Property, Collaboration and Innovation

Much of the initial work involved testing successive encapsulant formulations to identify the complex relationships linking silicone chemistry to superior LED performance and reliability. Dow Corning's proprietary understanding of these relationships became an incredibly valuable asset to its collaborators. Without it, customers would need to test encapsulant formulations for each new LED design. That, in turn, would cost precious money and time during a period when being first-to-market was critical to competitive success.

Dow Corning's collaborative research provided longer-term benefits as well. For example, its early studies of methyl- and phenyl-based silicone encapsulants showed phenyl technology offered superior optical performance and reliability. Through continued collaborative testing, Dow Corning optimized these high refractive index (RI) materials into encapsulants that could increase optical efficiency of LEDs by 7 percent, independently of improvements the chip, case or input power. In 2002, Dow Corning filed the basic patents for its optical phenyl resin encapsulants, and introduced its first commercial product a year later.

The strength of the Dow Corning's IP portfolio has become increasingly critical to continued innovation along the entire value chain.

For example, under the protection of its patents, Dow Corning was able to more freely share its research and test new formulations. This helped accelerate innovation of new high-RI, phenyl-based silicone formulations for successive generations of high-brightness LEDs that evolved from increasingly demanding applications, from TV backlights through today's general lighting design's.

As the competitive landscape has expanded, the strong IP protecting the company's commercial silicone formulations offer implied protection to LED designs that incorporate them. For example, the Korean Intellectual Property Office (KIPO) recently granted Patent 101499709, which protects the curable organopolysiloxane chemistry used to formulate Dow Corning® Optical Encapsulant products. The technology offers high-value benefits, such as improved light output, excellent mechanical protection and enduring gas barrier properties for enhanced reliability. The Korean patent, combined with Dow Corning's portfolio of application and material IP in a host of countries, allows customers along the global value chain to confidently sell their LED packages, lamps and luminaires. This confidence is increasingly critical to ensuring LEDs offer a credible, cost-effective alternative to conventional lighting. It takes only a few failed applications to raise doubts about the technology's viability.

Conversely, industry-wide defense of proven, patented and cutting-edge LED solutions - such as Dow Corning's - helps validate the competitive value of LED lighting as a whole. This, in turn, contributes to the future growth of the LED lighting industry. ■

**DOW CORNING**

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# Tech-Talks BREGENZ - Dr. Biing-Jye Lee, Chairman, Epistar



## Dr. Biing-Jye Lee

Dr. Biing-Jye Lee is the Chairman of Epistar Corporation, a world leading high brightness LED epiwafer and chip manufacturer, based in Hsinchu, Taiwan. He obtained a B.S. and a Ph. D degree in Chemical Engineering from National Tsing Hua University in 1980 and 1985 respectively.

Dr. Lee began his professional career as a research scientist and a project leader at Industrial Technology Research Institute (ITRI), where he and his co-workers have successfully developed the first 780 nm AlGaAs laser diode in Taiwan. From 1992 to 1994, he became the research manager of Optoelectronic modules department. Under his guidance, his group has successfully demonstrated the first AlGaInP based LD and LED in Taiwan. From 1994 to 1996, he was the director of Optoelectronic materials and device division, responsible for the initiation of AlInGaP, InGaN and AlGaAs epiwafer production program.

September 1996, he and his colleague spun off from ITRI and founded Epistar.

Dr. Lee has authored and co-authored over 40 technical publications. He also owns more than 35 patents. The Ministry of Economic Affairs awarded him for his contribution in the area of optoelectronic devices. He is now the Chairman as well as CSO of Epistar.

Dr. Biing-Jye Lee, Chairman of Epistar, had a discussion with Siegfried Luger and Arno Grabher-Meyer from LED professional about the latest trends and the future of LED, Laser and Solid-State lighting technologies. He also gave them his view on how the markets and technologies will evolve. In addition, Dr. Lee shared some of the highlights from this year's Light + Building as well as his view of current issues such as smart lighting, connectivity and new applications.

**LED professional:** Could you give us a short overview of Epistar's strategy and positioning within the LED business?

**Dr. Lee:** Epistar was founded in 1996. Right from the beginning we positioned ourselves as a pure chipmaker. Since then we have also started to focus on different wavelengths of LED chips. Our products range from the red, yellow, orange, green and blue - all the visible range - and lately also included some of the infrared and ultra violet. We are trying to bring the so-called "one-stop shopping" to our customers. We endeavor to cover the full spectrum range, infrared, visible and UV technologies.

**LED professional:** What are the main markets that you address?

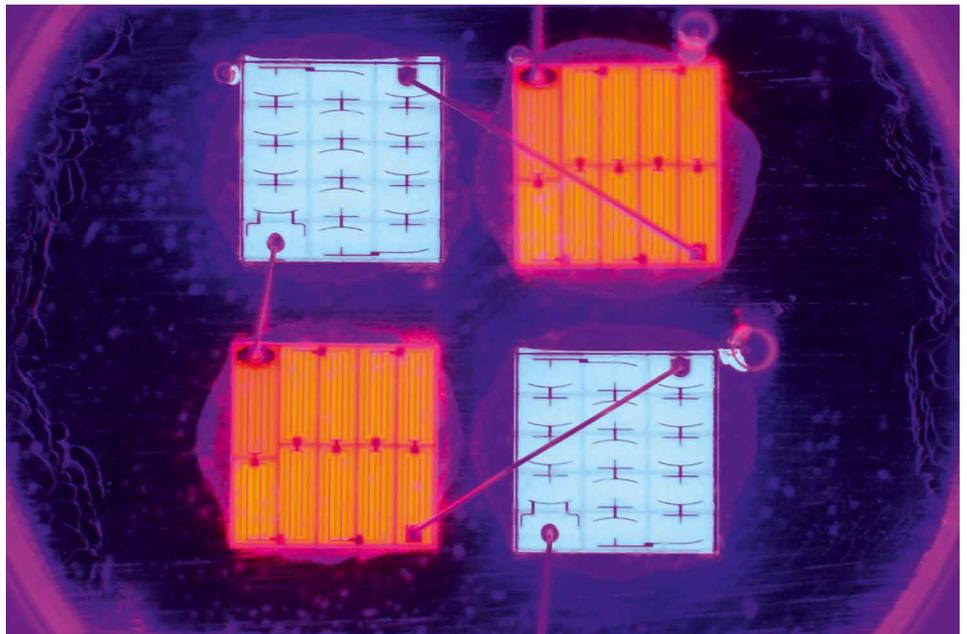
**Dr. Lee:** Currently, of course we still focus mostly on visible light. Backlighting and solid-state lighting need blue LEDs. In the future for micro-LED and smart, digital lighting you may need RGB mixing to support this market.

**LED professional:** What about Epistar's high-voltage LEDs with a combination of blue and red LED chips?

**Dr. Lee:** The blue/white LEDs plus the red chip still give you the highest performance but you need two channel controls. You need to control both channels because the two materials have different temperature characteristics.

The Department of Energy in the United States, is continuously testing former blue/red chip bulbs and they are still running after 40,000 hours. The decay in lumen output is less than 5% and the color shift is negligible. For low cost applications a pure blue/white LED approach might be preferred, but the market is currently also asking for higher CRI values.

**LED professional:** How does Epistar support system developments for specific markets and applications?



Epistar showed a combination of red and blue high voltage LEDs to generate PC converted white light in 2011 at LED Lighting Taiwan

**Dr. Lee:** To bring more value to the end customer, we started to work on an integrated service model. We approach, for example, the luminaire or TV manufacturers and address their needs. Then we look for the best solution within the complete supply chain. We have to involve companies with knowledge in phosphor, packaging, optics, thermal management, PCB designs, and electronics. According to the customer needs, we also have to modify our chips to meet their requirements. For example, recently we designed a new cost-effective and high-performance back-lit TV system. We have reduced the quantity of LEDs but we could improve the overall system costs and performance.

**LED professional:** Could you tell us about the Chip-Scale Packaging technology?

**Dr. Lee:** Epistar does have a highly sophisticated CSP technology in-house. For certain applications a semiconductor process during manufacturing is required. But in other applications our packaging

clients take care of the module and we provide the flip-chip that fits their needs.

**LED professional:** Some LED manufacturers have failed because they were competing with their own clients in some areas. What is Epistar's strategy when it comes to vertical integration?

**Dr. Lee:** History tells us that the supply chain will compress after a certain amount of development time. To some extent this happens especially when it becomes a more mature commodity -then the supply chain collapses. Epistar has strict plans to stay a chip player but we want to work closely with the customer. We call it "Virtual Vertical Integration or VVI model".

In certain cases Epistar's subsidiaries or joint ventures also offer module solutions to luminaire manufacturers with a complete integration of chips, drivers, and boards. This business is done through partner companies with packaging and driver technologies. Epistar will still remain focused on chips, but we invest in or co-work with

According to current market research it will take about 10 years for LED headlights to become mainstream. This is especially true of matrix headlights like this one from Hella/Audi. One reason for this is the long life time of cars (Credits HELLA)



other companies in order to offer solutions and new services.

**LED professional: Does this generate additional value?**

**Dr. Lee:** Yes, it does. Recently we found out that we can change some of our chip designs. For example, we have started working with a driver design company that has figured out the advantages of using high voltage. This company is confident that it could develop a new driver circuit, which is highly efficient, flicker free, and dimmable, by using the high voltage chips.

**LED professional: How do you see the market shares for SSL, TV and automotive?**

**Dr. Lee:** The percentage in revenue of solid-state lighting is roughly 45%. Worldwide, the high brightness backlighting LED market, is about 25% to 30% and automotive about 15%. Actually, since 2014 backlighting has been decreasing slowly and solid-state lighting has been increasing very quickly. I think solid-state lighting will go up to around 55-60% and backlighting will go down to around 15-20%. The rest of it will be divided

between signage, automotive and other applications.

**LED professional: Why is the automotive portion just 15%?**

**Dr. Lee:** The automotive industry changes very slowly because a car runs more than 10 years. So it takes a long time to change from a current technology to a new one. In general, LED output power relates to chip area and chip area means costs and costs mean dollars. The problem is that the high power application in automobiles, the headlamp, has not been changed to LED lighting yet in most cars. A market analysis showed that in 2025 forward lighting using LEDs would still only be about 30%. Right now it's at about 3% but it will take another 10 years to get to 30%. That is very slow.

**LED professional: What is your strategy in regards to GaN-on-Si technology and GaN-on-GaN technology?**

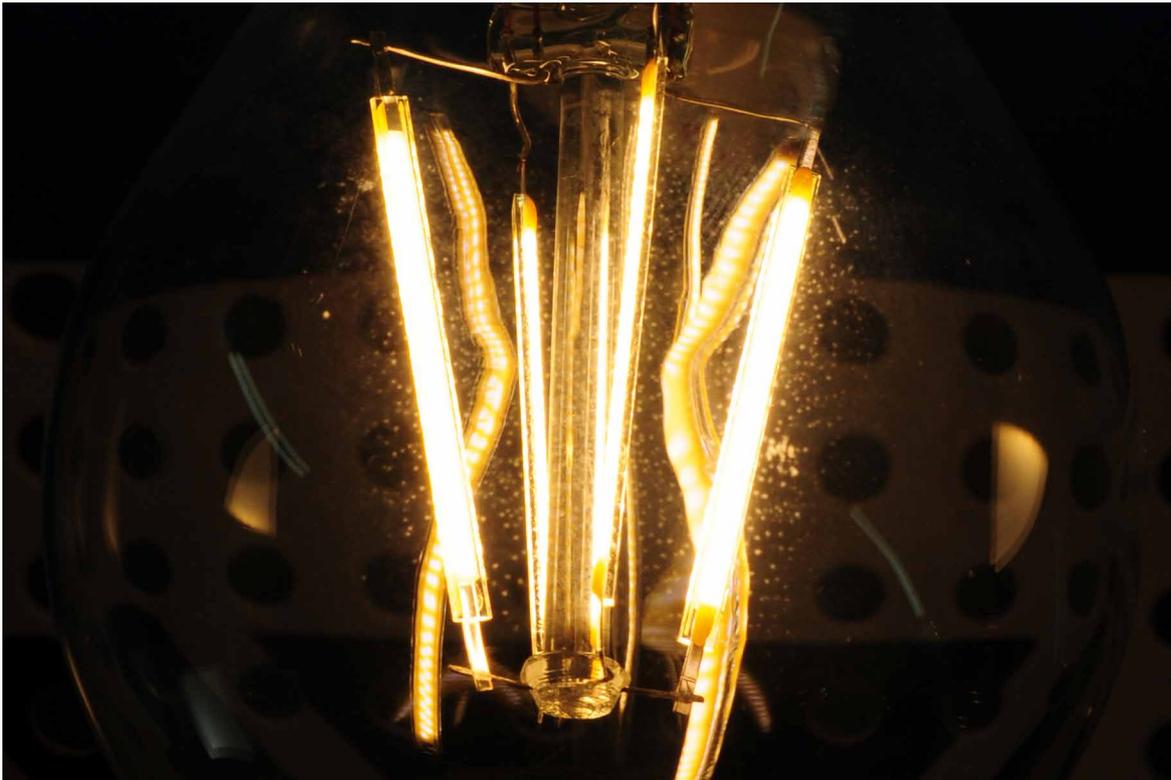
**Dr. Lee:** We have been working on GaN technologies for more than 10 years now. And we understand that it is extremely competitive in the backlighting and solid state lighting market.

Based on the core technology that we have on mature growing - we can grow GaN-on-Sapphire and we can grow GaN-on-Silicon as well.

But with lighting, it may not be practical right now to use GaN-on-Si unless you have a fully depreciated silicon line. Because everybody knows that the lighting business is very challenging when it comes to prices. We're just putting out this idea to let people know that we are working on this material even though we're not sure that it will be of value for this business. However, it does show good potential for electronic applications.

**LED professional: Could you give us an overview of Epistar's highlights at the Light + Building? What are your newest innovations?**

**Dr. Lee:** One highlight is the high-voltage design where we can put the electronic driver-on-board. Instead of a down-converter we're using a boost-topology, which is highly efficient and easier to design. For TV applications we showed new LEDs with smaller footprints. We're also working on so-called micro lenses in the chip or just on the



Because of their technical conditions, Epistar feels that the LED filament bulb market will be an interesting segment for LED manufacturers

surface of the chip. In addition to that, we showed a filament light bulb that was developed by one of our customers with color temperatures of 2200 K at our booth.

**LED professional:** How important is the filament market and what technologies are you using?

**Dr. Lee:** The filament market for decorative designs may count as about 15% globally but the classic retrofit market will decay over the next 10 years due to the long life time of LED bulbs.

In regards to the technology there is no place to get the heat dissipated so you cannot drive the chips in the high current density mode. You have to drive it in high efficiency mode - otherwise it would be too hot. That means we need more LED chips. The basic technology is the same.

**LED professional:** Are you also looking into horticulture applications?

**Dr. Lee:** Beside the decorative lighting applications, horticulture is also an interesting new application field for Epistar. We offer infrared,

deep red and blue LED chips, which is good because the mixing of specific wavelengths is required for different plants.

A good example is a customer that needs different kinds of lights in different wavelengths to make the plants grow faster. In the first stage they need a certain wavelength to start growth but in the second stage they need a different wavelength so the plant grows the leaves. The leaves grow and they are very green. In the final stage before they take the plants to the market they use different wavelength mixing and put the plant under stress. The stress makes the leaves turn red within 24 to 48 hours and then they are ready to be sold!

**LED professional:** Since you worked with lasers in the past I'm sure you know that there are activities going on for white light generation with lasers in top automobiles. What are your thoughts on laser lights with phosphor conversions?

**Dr. Lee:** Laser lighting has great potential. A laser-based design can be optimized optical-wise because it's coherent light. With laser light

the distances that one will be able to see could be up to 50% farther.

We have invested in a company that is working on laser. If they can come up with something good, we can jointly take it to the market. We can do the processing for them and grow the material for them and they can do the marketing or vice versa. We are still putting some effort into it.

15 years ago big LED manufacturers believed that the solid-state era would come and they put all their efforts into making the world's best high-power LEDs. But all of a sudden there wasn't high power - but rather - mid-power. Mid-power is the mainstream now and those companies have suffered a little bit with that change. So if you think that laser is going to be the only solution for future lighting you might end up seeing a lot of different applications that won't be possible or economical by laser.

**LED professional:** How does smart lighting influence your business?

**Dr. Lee:** No matter how smart, smart lighting gets - the LED chip stays about the same. But one thing that actually involves the LEDs is the

Smart lighting and the increasing demand for communication and connectivity calls for new communication methods as today's bandwidth is limited. This is the chance for LiFi in the future - probably beyond today's application ideas (Credits OLEDCOMM)

up-coming communication and connectivity. Everything is going "smart" and there is not enough bandwidth to carry all the messages to the same place at the same time. What they are thinking of, is to use 60 GHz Wi-Fi instead of the 2.4 GHz that they use today.

Because 60 GHz is also line of sight we can simply use the LEDs with the so-called Li-Fi instead of Wi-Fi. So that would change the situation. With Li-Fi people are looking for Gigabits per second. It's still a challenge but it's doable.

**LED professional: What are the next steps in smart lighting designs?**

Dr. Lee: Currently smart lighting is mostly driven by the communication signal or protocol such as Zigbee, DALI, Wi-Fi, and Bluetooth. Of course we hope that some of the visible light or some of the LEDs could be used in that kind of smart lighting as well. One other thing is that when they become really good we also expect a good growth of RGB mixing. Not just one color. And some of our competitors only have one color, which is blue, so we also expect that when smart lighting starts to happen, you will see more and better solutions with different colors. Not just warm white or cool white. But mixing because it will be made to your needs.

**LED professional: Thank you very much for your time and the insights into your company! Hope to see you in Bregenz again at the LpS 2016.**

Dr. Lee: Thank you. ■





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**We bring quality to light.**

# Light + Building Post Show Report: The Six Most Noteworthy Observations

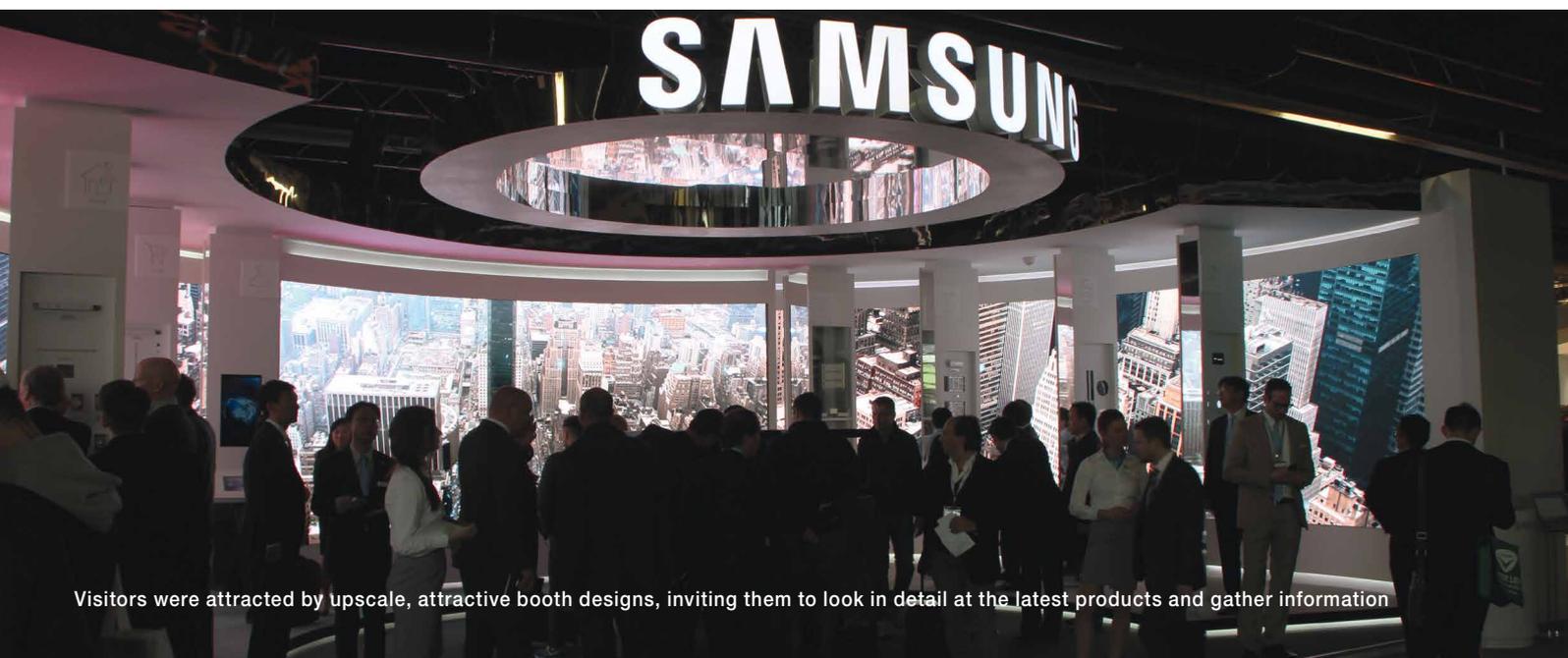
In the weeks and months before the show it was obvious that the major topics were going to be IoT and connectivity. There are many reasons for this. One is that LED lighting has become established but the big deals for smart lighting and human centric lighting are missing. IoT seems to be the way to improve communication and enable both smart lighting and HCL. Arno Grabher-Meyer from LED professional gives a summary of his impressions of the fair in regards to these topics, and beyond.

The Light + Building 2016 with about 2,500 exhibitors and over 216,000 visitors, closed its doors after one week. The visitors to the exhibition and numerous side events, ranged from technicians looking for information about components and/or applications, to lighting designers, architects and planners who went to see luminaire manufacturers and system providers, and on to installers looking for luminaires and installation material. The Light + Building offered the chance for them all to get

information about the latest trends and to connect with others. The majority of the companies and products were related to luminaires and installation material but there were also a vast amount of companies there displaying components and modules. Visiting all of them and getting detailed information in six days was next to impossible but I did have enough time to get a rough impression of the current business situation.

The times of big news and sensations in the LED lighting

business seem to be more or less over but that doesn't mean it is less exciting. And it certainly doesn't mean that it isn't worth visiting other exhibitions and events. On the contrary, if you look more carefully at the details and shift from a purely technical view to a more application oriented and solution-focused view, you'll find a lot of exciting information. The six most striking impressions, covering all the stages from the component level up to the system and application levels, will be summarized below.



Visitors were attracted by upscale, attractive booth designs, inviting them to look in detail at the latest products and gather information

## Diversification

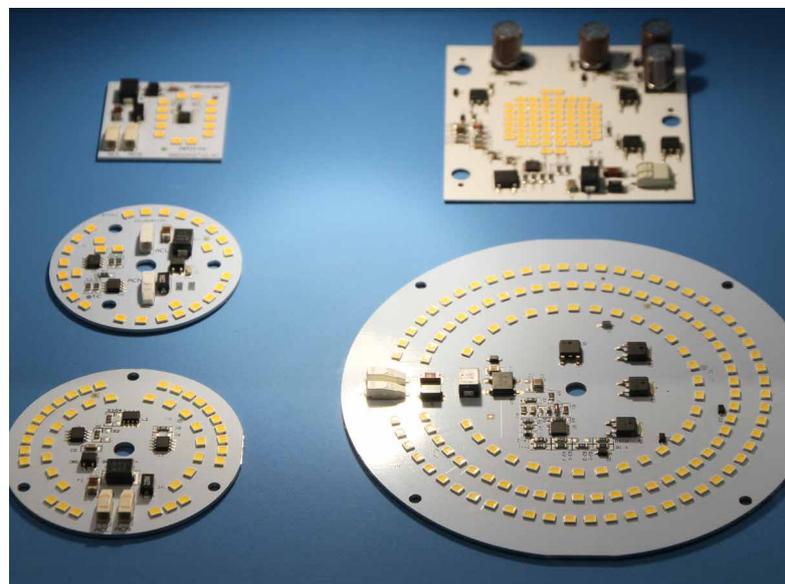
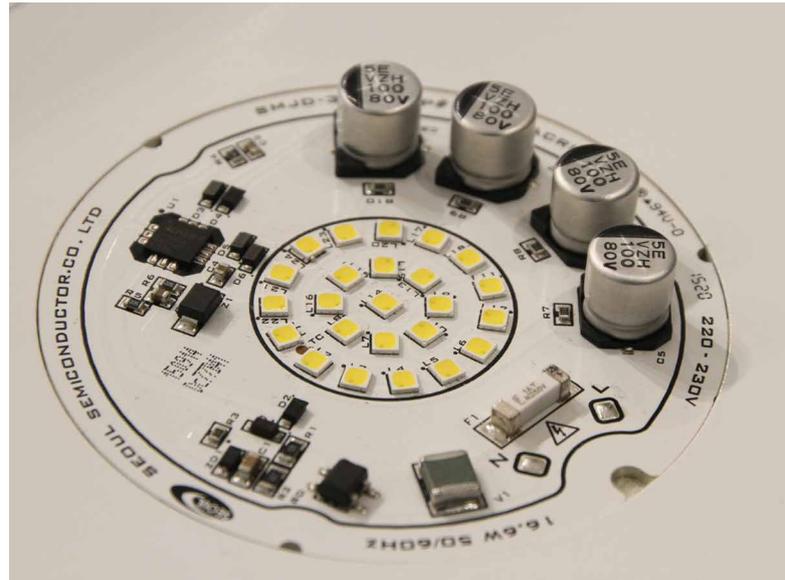
In the recent past LED manufacturers have demonstrated that they are quickly approaching the physical limits of light generation efficacy. The big manufacturers know that further improvements could help the environment or adversely support the rebound effect but from an economic point of view, improvements are great for the end-user, even if there aren't any big direct monetary paybacks. On the other hand, improvements support technicians and manufacturers in the designing of cheaper and more reliable products. And there has been a change in the ongoing race for the most efficient LED: The leading actor at the Light + Building 2016 was not the high power LED and not the subject of lumens per watt. Instead, the main topic was offering the right solution for the best system efficiency for different applications.

While in 2014 the focus was on high power LEDs, now the central issue is the progress of COBs and beyond that, mid-power LEDs (MP LEDs). This could be the consequence of the demand for high-power LEDs stagnating or even decreasing while the demand for mid-power LEDs has increased. Low cost mass production from Chinese government sponsored manufacturers has spurred manufacturers from other countries to try alternative strategies in order to generate unique mid-power applications. One common approach is the increase of efficacy with some mid-power LEDs clearly exceeding 200 lm/W. We hear manufacturers now claiming to have the world's most efficient, world's most reliable or world's most cost-efficient MP LED. And when we look at the Lumileds 3535 small package or the Everlight common 5630 standard package and CRI, the Samsung high CRI type and the Seoul Semiconductor multi-junction MP LEDs, they are all correct.

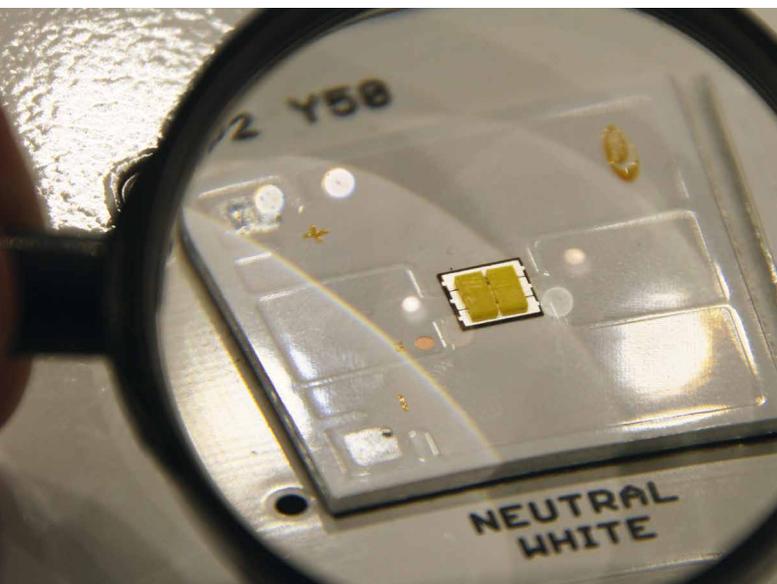
What is even more impressive than these record efficacies, however, are other improvements and approaches like lifetime and reliability. Longevity has been improved to the point of almost being equal to high power products.

The ongoing diversification in this business segment is especially remarkable. MP LEDs now have special properties that only HP LEDs had in the past. Things like a special white appearance, high CRI LEDs, high lumen density products that satisfy other relevant technical requirements with improved parameters can now be found in the portfolios of top tier LED manufacturers. The LUX 2835 by Lumileds is available in five configurations of light output and string voltage and ESD protection while their Luxeon HR30 LEDs are designed to operate for over 100,000 hours of continuous operation in harsh environments. Everlight has released 2835 packages in three voltages: 3 V, 6 V and 9 V at 0.5 Watts and two voltages: 6 V and 9 V at 1 Watt, and ultra-high efficiency versions of its low-mid-power 5630 package series. Seoul Semiconductor has made improvements on their Multi Junction technology LEDs in a 5630 package that support high voltage driverless designs and Samsung extended its broad MP LEDs portfolio with a high CRI version, the LM561B+ package. These are just a few of many examples.

One possible consequence for engineers is that their lives may have become a little more complicated due to the high number of different products. On the other hand, experienced engineers can now choose between optimized products according to their requirements whether they want to focus on performance, lifetime, light quality or cost-effectiveness.



Many of today's modules and applications are based on mid power LEDs. LED manufacturers, meanwhile, provide a broad spectrum of mid power LEDs with very different specifications ranging from multi junction high voltage LEDs to LEDs with high CRI or special white tones



Reduction in size and the number of components is certainly not new to this business but is becoming more and more common. While CSP are obvious proponents, due to new concepts, optics have become smaller and lower in height

## Minimizing Methods

The first thing that needs to be mentioned when we talk about minimizing methods is the Chip Scale Package (CSP). The newcomer at Light + Building 2014 has matured and is now well established in the portfolios of most manufacturers. However, most manufacturers agree that it is not the cash cow they had hoped for and that flip chip technology is still too expensive for many applications. Furthermore, many of these products are still lacking performance when compared to the competing standard LEDs. Nevertheless, the number of manufacturers providing this solution is growing and the top providers have already tailored these products for different requirements.

The latest developments in this field are CSPs with different half-width-angle emissions, CSPs with high CRI and CSPs with integrated primary optics. Some manufacturers are even leaving the mid power range and seriously approaching the high power domain with CSP LEDs. Besides a full line of CSP LEDs with different CRIs, Samsung currently offers a 3-by-3 CSP array capable of 10 W at approximately 124 lm/W. SSC also presented a tightly packed WICOP 2 CSP array. Prolight Opto featured their different solutions with and without primary optics, with and without phosphor as well as different color versions.

The weak point of this technology is lower efficacy compared to mid power products as can be seen in the figures above. This disadvantage can be partially compensated in one or the other application by some design advantages while manufacturers like Osram and Lextar are following another approach to achieve a similar reduction in size and system costs. They are also shrinking the package size to chip size but instead of using flip-chips they are still relying on conventional wire-bonded chip technology.

Miniaturization is also a topic beyond the LED itself. LedLink presented three generations of collimators side by side. The original first gen lens is the biggest one and still important when top UGR values are mandatory. The second and third gen series offer significant weight reduction and the latest lens especially reduces the overall product height giving new design opportunities.

On the chip level, this miniaturization trend is certainly supported by other markets like mobile devices or wearables. One just needs to think about many sensors that are now shrunken to sizes that were absolutely inconceivable some years ago without compromising quality and functionality. The full potential of this recent trend is not fully utilized yet in lighting applications and possibly bears a high potential for designers and luminaire manufacturers.

## Integration Approaches

Always a hot topic, and predicted for years, it started with driver on board and so-called driverless modules and is now visible on every level from chip scale to modules. LEDs, optics, thermal management as well as different electronics like drivers, sensors or controls are all involved.

Plessey could have been mentioned in the section on miniaturization, but they are going one step further in their approach. Not only is Plessey minimizing size, but they also aim to add supplementary components on the chip and LED package level, reducing the overall

number of components of the complete system. The difference between their approach and that of most competitors is that they start with the production of GaN-on-Si based surface-emitting LEDs and end up integrating a unique modular chip scale optic. The company also confirmed that they are investigating further integration opportunities of their GaN-on-Si technology.

The Epistar approach of allowing for higher integration, which, in turn allows for miniaturization, is going in the other direction. They showed their GaN-based transistor (see the LED professional report in LpR 50) used in a DoB module. In combination with HV LEDs, the GaN-IC provides a significant improvement in overall system efficiency and a reduced BOM and therefore a miniaturization of the system. At this stage of development it could not be disclosed whether this development would be integrated with the LED on a chip level.

Another example that offers both higher integration and minimized dimensions comes from MAZeT. The company introduced the fully integrated MTCS-CDCAF sensor chip solution with an I<sup>2</sup>C interface to guarantee defined light. The technology for the sensor is similar to the well-established MAZeT MTCSxxx XYZ color sensors.

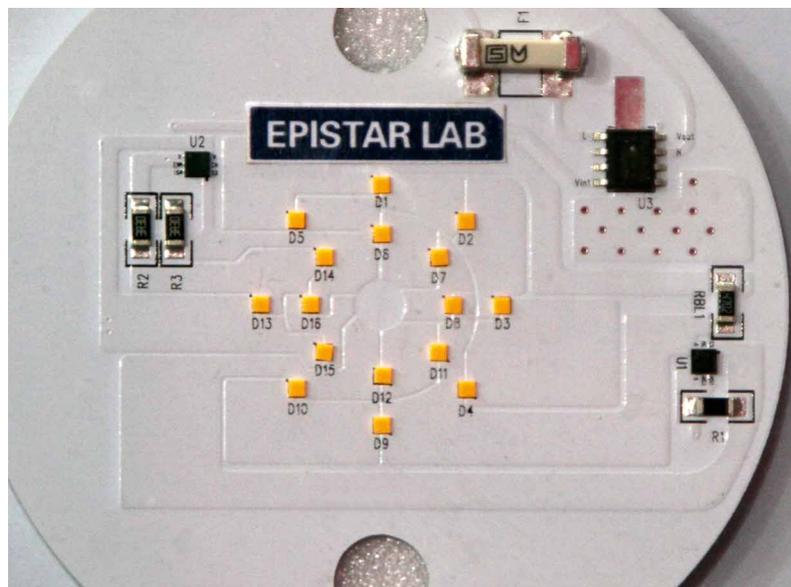
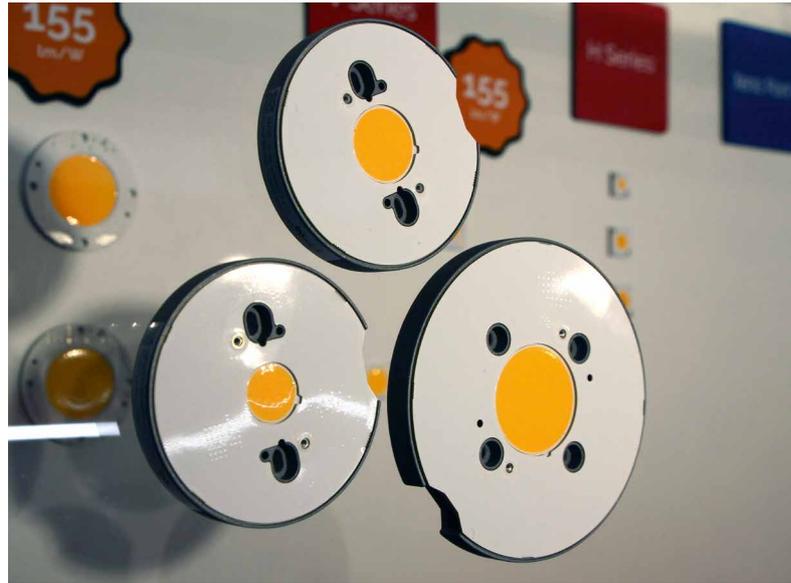
On a module level, many more companies are pushing towards higher integration levels. The XIM modules that were introduced by Xicato at the Light + Building 2014 have been enhanced by adding additional controls and wireless capabilities. A smart new feature is having the antenna close to the LED. According to Xicato, this position will improve wireless connection quality in recessed applications because shielding effects from metal enclosures are minimized.

In the meantime, other manufacturers have started offering modules with extended connectivity and higher integration levels. Bridgelux's Board of Directors even decided to spin off their own business and sell the core business to an investment group. The Xenio LED module platform integrates local intelligence and communications capabilities and is based on the Bridgelux Vero® Series LED arrays.

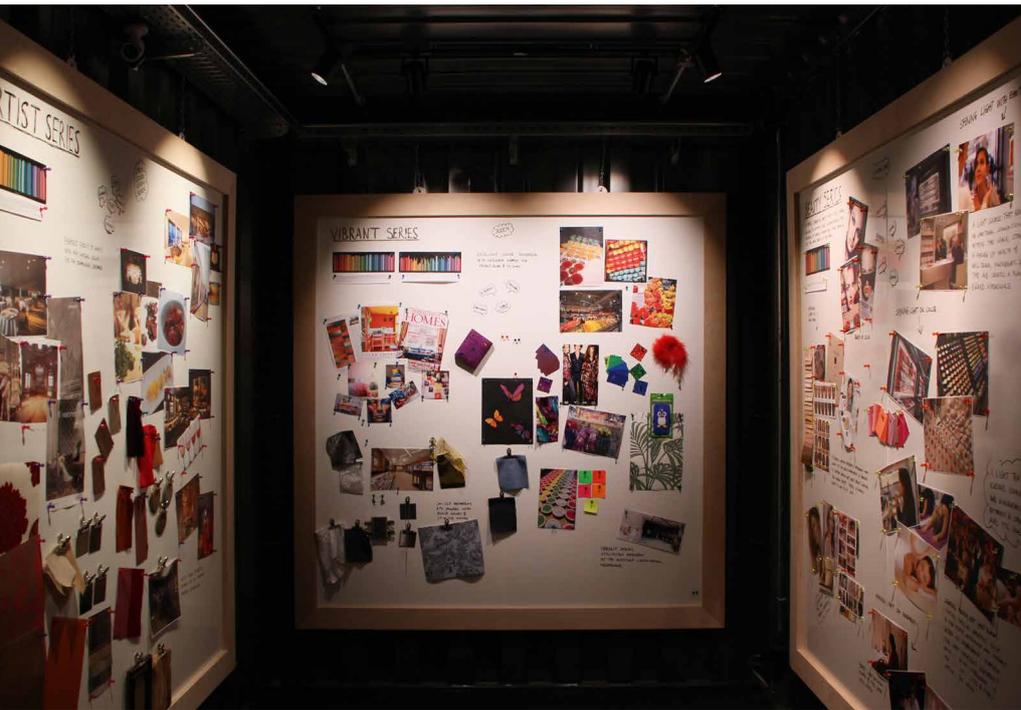
Viapaq has come up with a product that cannot be ignored even though it can't be called compact. They demonstrated a unique, single LED module that generates 4,000 or 6,000 lumens, depending on the selected type, and it only has one 2-pole mains connector for direct implementation for luminaires with a length of 1.2m and 1.5m.

The list of companies providing DoB solutions seems to be growing on a daily basis. Megaman pointed out the importance of this group by casing an eye upon the market and starting to offer an increasingly broad range of modules. It's not surprising when you consider the synergies between the production of lamps and highly integrated LED modules.

The trend towards higher integration is known in other industries and it was only a matter of time before it prevailed in LED lighting. The reasons for it to have taken hold now are manifold: Applications requiring this type of solution have been identified; The volumes requested have become reasonable and cost issues are also moving in that direction; The component efficacy has reached a level that makes thermal management more controllable; Adequate lifetimes for the designated applications can be achieved with proper design. It will be interesting to watch what is coming over the next few years.



Integration is omnipresent, sometimes combined with miniaturization. Modules have integrated controls and wireless communication. New transistors allow a reduced BOM. Sophisticated primary optics, as integrated part of the LED die, render secondary optics obsolete



## Light Quality

Quality is always relevant but several manufacturers, for example, Nichia, Xicato and Soraa, have started to address “light quality” and are demonstrating their commitment to it in various ways. This year again, Nichia showed an impressive portfolio of high CRI and specialty lighting products. A new study that showed that all color metrics are questionable when it comes to specific applications prompted Xicato to design a new line of products for cosmetics and Soraa addressed light flicker and LED drivers, a topic that is unconventional for a manufacturer whose business is based on LED chip technology.

Two other companies that are attempting to improve light quality are Osram Opto and Toshiba Materials.

Osram Opto demonstrated how different whites of the same CCT can appear even for 1SDCM binning depending on if the 2° or 10° color space is used for binning. To improve overall color consistency, they propose to switch to the 10° color space, at least for critical applications, and offer their Soleriq S13 in this binning from now on.

In collaboration with TOL Studio, Toshiba Materials planned their new TRI-R LEDs, which don't only provide high CRI but also offer a continuous spectrum, without spikes or absence of specific colors with a spectral distribution that is closest to sunlight. This quality aspect cannot be described with CRI or other currently used color metrics and this unique light quality is especially useful in the field of museum and arts. Similar to conventional products with extreme CRI, the efficacy is certainly affected, but the improvements of the past years still allow a remarkable efficiency of over 80 lm/W.

Light quality has many different aspects and strongly depends on the application. While luminaire manufacturers sometimes ask for the impossible, not all component manufacturers have the same attitude when it comes to quality. However, they are increasingly recognizing the importance and are starting to expand their services and product range. It seems that soon any quality requirement will be able to be satisfied without the need of costly customized products.

**Just two examples of how companies understand light quality: Three different whites from Xicato for different applications, and Osram's demonstration of 1SDCM binning for a 2° versus 10° viewing angle**



### Market Adjustment

Anybody who was looking for big news about OLEDs was probably disappointed this year. It looks like the OLED train has got stuck instead of picking up speed. In the early phase of OLED technology many more companies showed OLEDs and OLED modules. Today, even in applications, the exhibits were limited. On a component level more or less two companies stood out from the crowd: OLEDWorks and LG Display, formerly LG Chem. Both companies demonstrated OLED panels and flexible OLEDs that provided performance that is the prerequisite for modern general lighting applications.

However, many of the applications for which they were designed still lack when it comes to performance when compared to LED solutions. But perhaps comparing them to LEDs isn't really fair since their development started years later. Right now costs and performance are not the only and possibly not the most important factors limiting the OLED applications. Drivers and

The offering of OLED modules was limited to a handful of companies. The two that stood out, LG Display and OLEDWorks, demonstrated a broad program of interesting OLED solutions with reasonable performance data, from flexible OLEDs to rigid OLEDs with various CCTs, CRIs, luminosity and efficacy





controls are very important next to the light source but they sometimes compromise the design that the OLED, itself, would support, minimizing the design advantage over the LED solution. The limited panel size also prohibits satisfactory solutions and raises the question of whether or not the OLED is really worth the extra cost.

Developments based on inorganic LEDs offer great design solutions for planar lighting with various useful features and properties. Even 3-dimensional and flexible designs are possible. The latest developments from Cooledge Lighting offer color tunability that supports the latest HCL trends. Design LED's Light Sheets are water resistant. Newcomer, Carpetlight, developed an ultra-light textile solution that offers a high quality light and is available in color tunable versions, as well.

It is therefore not surprising that the question about the future of OLEDs in general lighting was also present in discussions at the OLED manufacturers' booths. They would have to consider the evolution of rigid and flexible planar LED products over the past few years. The remaining manufacturers of OLEDs may feel a little anxious when big competitors like Philips, Osram and Tridonic reduce their commitment to OLED technology or stop showing them altogether, especially after their relatively massive presence in 2012 and 2014. There are certainly many applications for OLEDs but good ideas and a system approach are required before they succeed in taking part in the mass market - and this will take a lot more time than at first anticipated.



**Different inorganic LED based products are competing with OLEDs that have very similar or interesting alternative design solutions for an application. Their higher lumen per Euro solutions make them serious competitors**

### Communication Technologies

Communication technologies seemed to be all about connectivity, communication and IoT. IoT was all pervading, but incorrect use of the term has led to confusion especially since the term IoT was sometimes used synonymously for smart lighting or vice versa. Sometimes the three terms IoT, smart lighting and HCL were mixed up and very often the underlying network technology was marketed as IoT.

The community seemed to be even more confused or conflicted when it came to questions about the functionality, purpose and use case of IoT. Some companies considered IoT as a new name for common controls technology with an added web interface while others had a

much more visionary understanding. They explained what else was possible and what could be done beyond lighting. The only common denominator is the fact that all companies are still searching for a clear business case and a business model.

This situation has often led to very interesting and sometimes philosophical discussions about IoT. Discussions ranged from asking questions like, "Does it make sense?" "Is it needed?" and "Is it worth the extra money?" to dialogues about appropriate networking technologies, the pros and cons of proprietary lighting networks with gateways versus direct IP based systems and safety, security and privacy issues. But as long as there was no real understanding of what IoT meant, the discussions weren't very valuable. Technical aspects often got cut short even though very interesting technologies were presented. The following four proposals stood out at L+B:

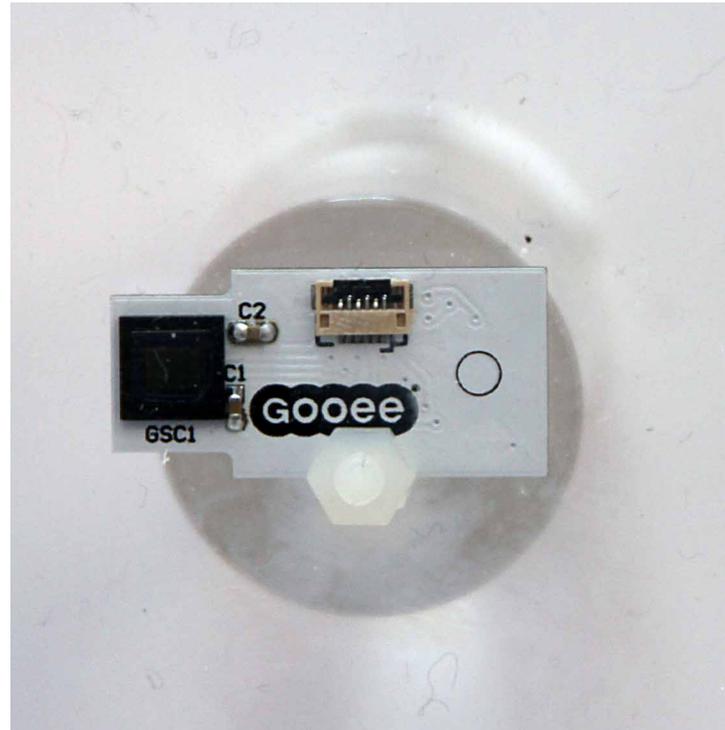
Goeee designed their IoT environment around their unique, multifunctional sensor ASIC. Facing downwards - the sensors detect motion, direction, footfall and ambient light levels and temperature. Upwards - the sensors monitor light output, color temperature, quality and operating temperatures. Furthermore, they calculate the luminaire's life period from its beginning. In addition to their proprietary Wireless Interface Module, or WIM, Goeee relies on a Bluetooth Mesh based, scalable, distributed gateway environment.

As a leading contributor to the Bluetooth SIG Mesh Working Group, Silvair's solution is Bluetooth 4.0+, aka Bluetooth Low Energy (BLE) based. The company demonstrated their full-stack module, a combination of hardware and software solutions designed to meet the challenging requirements of the commercial lighting environment. In addition to the powerful wireless

connectivity engine, each such module contains a set of software-defined lighting features.

Casambi also relies on advanced Bluetooth 4.0+ technology. The integrated iBeacon technology extends the functionality of their modules far beyond lighting applications, but also allows for interesting approaches in lighting applications. A detailed explanation of the features, technology and application was published in LED professional Review, issue number 54 (LpR54). We saw Casambi's technology implemented in many products at the show.

Tridonic's massive commitment to IoT was an integral part of the products shown at the Zumtobel Group booth. However, for those who were especially interested in details and the Tridonic's vision, an extra showroom and presentations were arranged outside the fair at the



A number of different approaches built around the core competencies and core technologies of the respective manufacturer were presented and while the basic idea of IoT still needs further development, it has great potential for many applications



Palais Livingston. Their top-level system, net4more, is based on IPv6 for low power networks, and 6LoWPAN for wireless. Tridonic started the development of net4more before the OpenAIS project and therefore was interested in becoming a leading member of the project. While net4more is not a direct derivative of OpenAIS, it shares synergetic properties. During the project some new ideas were born and it became evident that there was still a need for harmonization to satisfy the needs of home automation, lighting and the telecom industry. Therefore, additional efforts have to be made before the OpenAIS solution can become a standard. But net4more is already designed in such an open way that it is possible to change over and merge both solutions easily at any time (more information on this can be read in LpR 54).

There were only a few other companies that presented outstanding, new, straightforward concepts. Conservatism, a distinct characteristic of the lighting industry, was prevalent. Simply adding a web interface or gateway to a conventional DALI system (or a proprietary system) was the standard solution seen in abundance. The missing clear business case and a business model and uncertainty about the future standard may be the main reasons that many companies are reluctant. However, most companies presented a Cloud-based solution and talked about IoT, often advertising the advantages beyond lighting.

## Summary

You may be asking yourself why technologies such as LiFi are not covered in this report. The answer is that the primary focus was on technologies directly related to general lighting. While LiFi, for example, is a very interesting idea, it currently has no relevance for the given lighting tasks. Right now this technology is a one-way communication for some very specific tasks, although I believe it has great potential for the future. The trends and topics discussed were more obvious and selected because of their relevance to general lighting.

In some ways, Light + Building 2016 was different to preceding shows in that virtually no striking innovations were on display. The industry seemed to be more concerned with light quality, practicability and how to support the production of better light at a reasonable cost. Application specific light quality beyond the established color metrics, flicker issues and color consistency are clear signals that need to be addressed in the future.

Another indication is the ongoing diversification: Moving from the high-power segment to mid-power LEDs to allow for better and more application dedicated lighting solutions. This is also the miniaturization of LEDs through CSP technology and the simplification and miniaturization of other components and technologies for a reduced component count and therefore, new design opportunities.

The higher level of integration also supports these opportunities.

Turning away from the prominent display of emerging technologies that are almost exclusively only useful for special applications, leaving this field to the true specialists was another remarkable step. It seems as though the OLED market has been left to the specialists while established lighting companies are promoting their cash cows on the mass market.

The desire for better controllability of LED lighting is having a revival, IoT is the new catchphrase and many interesting technologies have been adopted. However, discussions were often not about controllability but rather the need for a control system and the capabilities of such a system beyond lighting, even though there seems to be no clear idea of the use and business cases.

All in all, the fair showed that the lighting industry is in motion. It is seeking new and realistic ideas and approaches. Semiconductor companies better understand the needs of luminaire manufacturers and can now provide the products needed. Newcomers are stimulating the industry and established lighting companies have managed the transition from ponderous dinosaurs to semiconductor driven, modern, smart, swift acting companies. If we look at it from that point of view, the show absolutely aroused expectations for an exciting lighting future. ■

**Version 4 COB  
Attaining 150 lm/W**



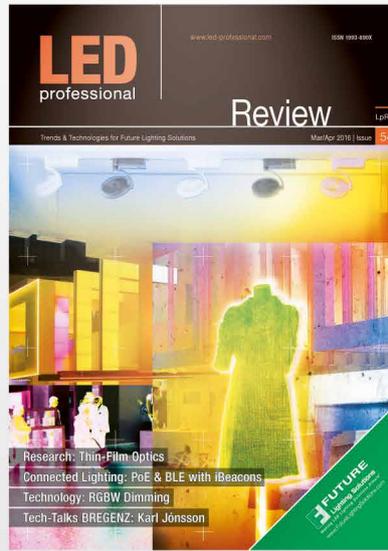
## Lextar Debuts 150 lm/W COB in Typical Conditions $T_j=85$

Lextar launches Version 4 COB lineup bringing 15% higher flux efficacy (up to 150 lm/W), quality and cost competitive products for versatile lighting applications from indoors to outdoors and commercial lighting. The performance upgrade is based on improvements in both chip die development and also package design. The new lineup also provides wide range of luminous flux and various colors, and wide selection of connectors and optical part solutions. Thanks to Lextar's vertical integration capability, it provides high quality and rapid development.

For more details see [Lextar.com](http://Lextar.com)

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# Trends & Technologies for Future Lighting Solutions.

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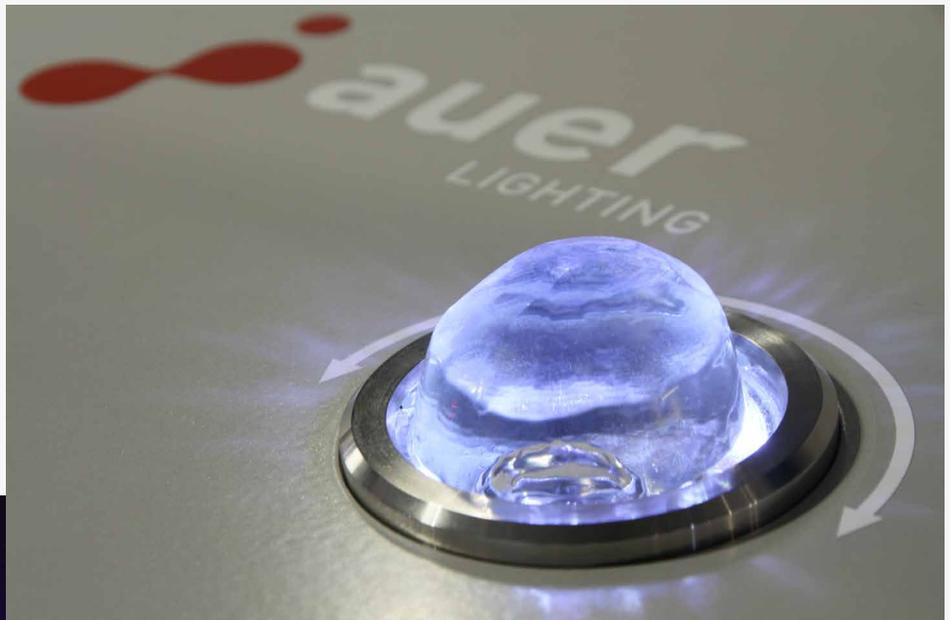
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## SOME ADDITIONAL TIDBITS FROM LIGHT + BUILDING 2016

It is a tradition for manufacturers to spark a firework of product launches at the Light + Building. A small selection of this year's new products and interesting exhibits are depicted on the following two pages.

► **Auer Lighting** highlighted their new 360° LED Outdoor Lens. The clever concept addresses various street lighting types with just one 360° lens geometry. The asymmetric light distribution can be adjusted by rotating the lens holder. By adding more lens modules to the system, light output can be tailored to meet individual needs.



◀ **Soraa** brought an array of LED samples that showcased their unique triangular dies. The crystal lattice structure of GaN-on-GaN wafers makes it possible to cut triangular dies. The advantage of this geometry is that, compared to squares, extraction losses are reduced.

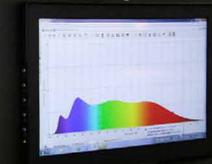
► **BJB** introduced several new mounting systems. One is a Zhaga Book 3 compatible module that can be used in fully automated lines for high capacity. There is also a manual mounting tool available for small series and prototyping. In addition to easy mounting, this system ensures that the contact to the heat sink is optimized under various conditions.





### Not disturbing Circadian rhythm

We believe the biological function of human is adjusted by spectrum of sunlight and its variation.  
Circadian system with continuous color day is color temperature and spectrum of sunlight by varying temperature range of color temperature and reproduced spectrum of sunlight.



◀ **TRI-R** offers CoB LEDs and systems that provide a continuous spectrum without the gaps or excessive peaks that conventional LEDs have. The illuminated model demonstrates that the spectrum is very close to the spectrum of sunlight and is available with different CCTs. This product is based on Toshiba Material Co. Ltd.'s technology.

▶ **LMT Lichtmesstechnik GmbH Berlin**, a renowned light measurement specialist, introduced their brand new KUKA robot based goniometer. While the use of KUKA robots for measurement tasks is not new, LMT made significant changes and improvements to the software to better accommodate light measurement tasks.



◀ In addition to their components and modules, **Lextar** showed some luminaire prototypes that proved their ODM design and manufacturing capabilities.

# Luminescent Glasses and Glass Ceramics for White Light Emitting Diodes

Luminescent glasses or glass ceramics represent an interesting alternative to LED phosphor due to their high thermal and chemical stability. A series of rare-earth doped glasses are investigated for their potential application as photon converters for solid-state lighting applications. Franziska Steudel, Sebastian Loos, Bernd Ahrens, and Stefan Schweizer from the Fraunhofer Institute and the South Westphalia University of Applied Science respectively, show that the color coordinate of double-doped glass can be varied over a broad spectral range by changing the rare-earth doping ratio accordingly. In addition, double-doping allows for a change in the color coordinate by using different excitation wavelengths.

Glass is very versatile and a good host for rare-earth (RE) ions; it provides high optical transparency, good RE ion solubility, and can be cast in almost any shape or size. Luminescent glasses have attracted much attention in the last decades, in particular for lasers, optical fibers, and optical amplifiers [1]. The influence of the glass host on the optical properties of the embedded RE ions is weak, since the incompletely filled 4f shell of the RE is shielded by the surrounding 5s<sup>2</sup> and 5p<sup>6</sup> orbitals [2]. The position of the RE energy levels is similar for different matrix materials [3], whereas the intensity of the transitions varies with the crystal field and the phonon frequency of the host [4].

Matrix materials with low phonon energies are preferred, to avoid non-radiative relaxation, in particular, for high-efficiency applications. Borate glass is a suitable optical material with high mechanical, chemical and thermal stability [1, 5]. A widespread interest in borate glass is recorded by multiple

publications on spectroscopy of RE ions in borate glasses in 2014 [6–11]. Compared to crystalline matrix materials, borate glass has a relatively high non-radiative transition rate for transitions within the 4f shell where one phonon or two phonons are involved, but for more than two phonons, the situation is reversed [12, 13]. The maximum phonon frequency of borate glass is 1,400 cm<sup>-1</sup> and thus higher than for other glasses, e.g. 1,200 cm<sup>-1</sup> for phosphate and 1,100 cm<sup>-1</sup> for silicate glass [14].

The RE ions Eu<sup>3+</sup> and Tb<sup>3+</sup> have a great technological relevance. Their red and green luminescence is used in cathode ray tubes, fluorescent lamps, and plasma displays and have therefore been intensively studied. In addition, Tb<sup>3+</sup> was found to be a good sensitizer to enhance luminescence efficiency of Eu<sup>3+</sup> via energy transfer [15].

In the last years, Eu<sup>3+</sup> and Tb<sup>3+</sup> owned increased interest as a phosphor for white LEDs. Traditional white LEDs combine

a blue LED chip and a yellow YAG:Ce<sup>3+</sup> phosphor [16]. However, this method has a low color-rendering index and high color temperature due to a lack of red emission. For white light generation, an Eu<sup>3+</sup> and Tb<sup>3+</sup> doped phosphor can either be combined with a blue LED chip or with a third RE ion emitting in the blue such as Eu<sup>2+</sup> [17, 18], Ce<sup>3+</sup> [19, 20], or Tm<sup>3+</sup> [21, 22] excited with an ultraviolet (UV) LED chip. With a three-color phosphor the light output is very low due to the lower efficiency of a UV LED compared to a blue LED [23].

In this work, Eu<sup>3+</sup> and Tb<sup>3+</sup> double-doped borate glass is investigated for its potential as a photon converter. Changing the Eu<sup>3+</sup>-to-Tb<sup>3+</sup> ratio enables a continuous shift within the green to red spectral range. In addition, double-doping also allows for a change in the color coordinate by using different excitation wavelengths: A fast switch from green over yellow to red color coordinate is possible by choosing the excitation wavelength accordingly.

## Experimental Details

Borate glasses using barium oxide as a network modifier are prepared. A ratio of two moles of boron oxide ( $B_2O_3$ ) and one mole of barium oxide (BaO) is used. In this ratio the glass network consists of the highest possible amount of four-coordinated boron [24]. The glasses are additionally doped with  $Eu_2O_3$  and  $Tb_2O_3$  for optical activation. The nominal chemical compositions of the samples are summarized in Table 1.

The chemicals are weighed in a platinum gold crucible (Pt/Au 95/5) and melted at 1100 °C for approximately 3 h. The melt is then poured onto a brass block at 500 °C which is below the glass transition temperature of barium borate glasses of  $T_g = 605$  °C [25]. The glass is kept at this temperature for 3 h to eliminate residual mechanical and thermal stresses before being slowly cooled to room temperature.

Absolute photoluminescence (PL) quantum efficiency measurements are performed with a commercial quantum yields measurement system (Hamamatsu C9920-02G) coupled to a 3.3 inch integrating sphere with a xenon lamp (150 W) as excitation source and a photonic multichannel analyzer (PMA 12) as detector. The quantum efficiency is determined from the emission spectra in the spectral range from 470 nm to 900 nm.

Temperature-dependent PL measurements are performed with a

Composition / mol%				RE-Content / at.%
$B_2O_3$	BaO	$Eu_2O_3$	$Tb_2O_3$	
66.00	33.00	1.0	-	0.50 / -
66.00	33.00	-	1.0	- / 0.50
65.93	32.97	0.1	1.0	0.05 / 0.50
65.67	32.83	0.5	1.0	0.25 / 0.50
65.33	32.67	1.0	1.0	0.50 / 0.50

custom-built fluorospectrometer (S&I Spectroscopy & Imaging GmbH FluoroVista) comprising a xenon lamp (75 W) coupled to a 300 mm focal length monochromator (Princeton Instruments Acton 2300) for excitation and a peltier-cooled photomultiplier (Hamamatsu R943-02) coupled to a second 300 mm focal length monochromator (Princeton Instruments Acton 2300) for detection.

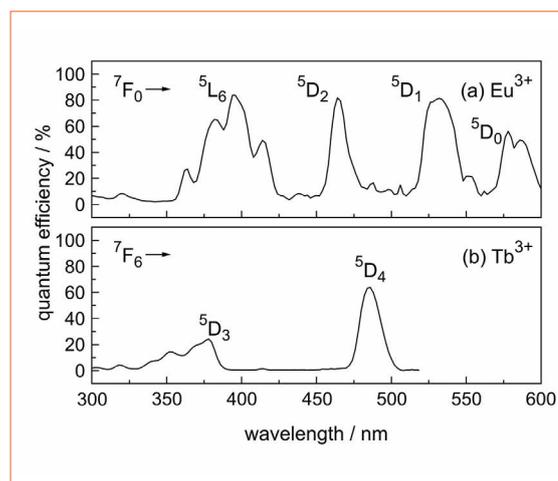
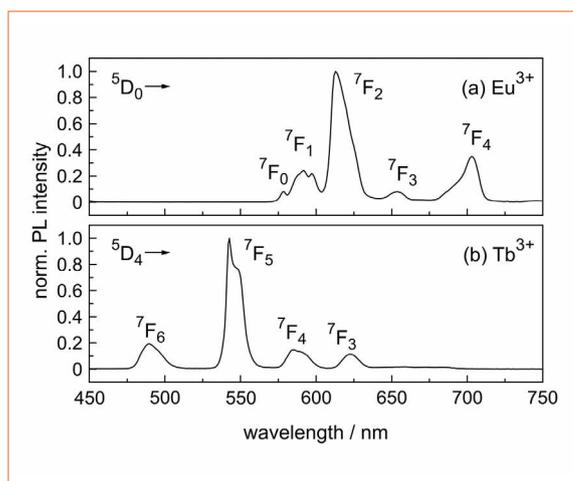
## Results and Discussion

### Rare-earth ion luminescence and quantum efficiency of single-doped borate glass

Though the spectral positions of RE ion emission are well known [2, 3, 26], the transition intensity ratios vary due to differences in crystallinity and phonon frequencies of the host material. The emission spectra of  $Eu^{3+}$  and  $Tb^{3+}$  single-doped borate glasses are shown in Figure 1. Upon excitation at 393 nm, the  $Eu^{3+}$  doped glass (Figure 1a) shows the typical  $Eu^{3+}$  emissions in the red spectral range, which are caused by transitions from the  $5D_0$  state to the ground state levels  $7F_0$  (580 nm),  $7F_1$  (592 nm),  $7F_2$  (611 nm),  $7F_3$  (652 nm), and  $7F_4$  (700 nm). The

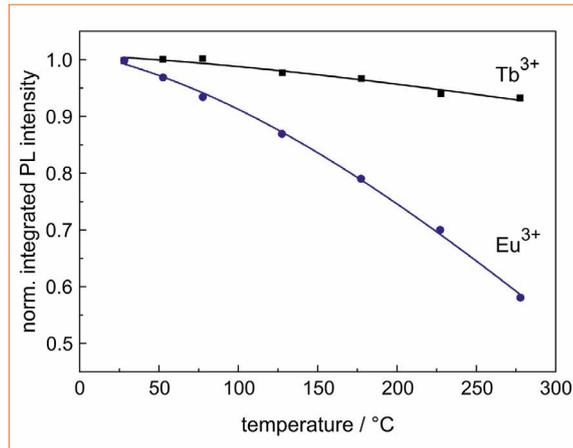
electric-dipole transition  $5D_0$  to  $7F_2$  is hypersensitive to variations in crystal symmetry [2]. The high intensity of this transition in borate glass indicates the amorphous nature of the matrix material with low inversion symmetry for the  $Eu^{3+}$  ion. In Figure 1b, the typical  $Tb^{3+}$ -related emissions at 490 nm, 543 nm, 583 nm, and 622 nm can be assigned to transitions from the  $5D_4$  excited state to the ground state levels  $7F_6$  ( $J = 6, 5, 4, \text{ and } 3$ ), respectively.

For both RE ions, emissions in the blue spectral range (from higher energy levels) are quenched due to the high maximum phonon frequency of  $1,400\text{ cm}^{-1}$  in borate glass [14]. However, the maximum quantum efficiency of the transitions observed is up to 86 %. Figure 2a shows the spectrally-resolved quantum efficiency of a 0.5 at.%  $Eu^{3+}$  doped borate glass: The transitions at 393 nm, 484 nm, and 530 nm provide quantum efficiency values higher than 80 %. For the 0.5 at.%  $Tb^{3+}$  doped glass (Figure 2b), the QE has its maximum at 464 nm with approx. 63 %. For wavelengths shorter than 350 nm, the QE is significantly reduced due to base glass absorption.



**Figure 1 (left):** Normalized emission spectra of borate glass doped with (a)  $Eu^{3+}$  and (b)  $Tb^{3+}$ . The  $Eu^{3+}$  excitation was carried out at 393 nm,  $Tb^{3+}$  was excited at 370 nm. The emission transitions are indicated

**Figure 2 (right):** Quantum efficiency spectra of borate glass doped with (a)  $Eu^{3+}$  and (b)  $Tb^{3+}$ . The main transitions are indicated



**Figure 3:** Temperature-dependent normalized photoluminescence intensity of  $\text{Eu}^{3+}$  and  $\text{Tb}^{3+}$  single-doped borate glass, recorded under 376 nm and 395 nm excitation, respectively

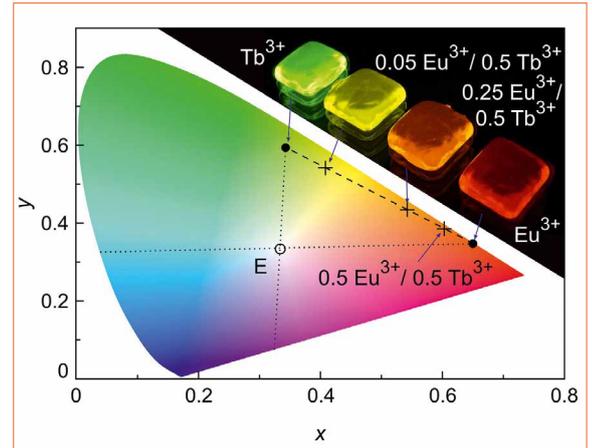
### Temperature stability

For white LEDs, the temperature stability of the phosphor on top is of vital importance. During operation, today's LEDs reach junction temperatures of 150°C and even 200°C in case of high-power LEDs. The high junction temperatures lead to a significant change in color appearance [27] since the phosphor emission intensity decreases with increasing temperature. There is a clear need for color-stable phosphors.

Figure 3 shows the temperature-dependent photoluminescence intensity of  $\text{Eu}^{3+}$  and  $\text{Tb}^{3+}$  single-doped glasses. Each emission spectrum is integrated and normalized to the value at room temperature. At a temperature of 275°C, the intensity for  $\text{Eu}^{3+}$  and  $\text{Tb}^{3+}$  doping decreases to 58 % and 93 %, respectively. For both RE ions, the so-called quenching temperature, i.e. the temperature at which the intensity amounts to 50 % of its initial intensity, is thus approximately 300°C for  $\text{Eu}^{3+}$  and even significantly higher for  $\text{Tb}^{3+}$ . For comparison, the quenching-temperature of the conventional LED phosphor  $\text{YAG}:\text{Ce}^{3+}$  lies at 270°C [28]. Although the intensity of the spectra decreases slightly, the spectral behavior does not change, i.e. the color appearance is stable in the investigated temperature range [29].

### Color mixing for solid state lighting with double-doped glass

Figure 4 shows the color coordinates of the  $\text{Eu}^{3+}$  and  $\text{Tb}^{3+}$  single-doped borate glasses in the CIE (Commission internationale de l'éclairage) color space chromaticity diagram determined from the corresponding emission spectra (Figure 1). Both RE ions are close to the edge of the CIE chromaticity diagram. They provide high color saturation since the blue emissions are suppressed by the high phonon



**Figure 4:** CIE color space chromaticity diagram with point of equal energy, E, and the color coordinates for the  $\text{Eu}^{3+}$  and  $\text{Tb}^{3+}$  single- (full dots) and double-doped (crosses) borate glasses under 380 nm excitation. The dotted lines indicate the complementary blue part. The inset shows four of the five glasses under UV illumination

frequencies of the borate host. Compared to  $\text{Eu}^{3+}$ , the  $\text{Tb}^{3+}$  emission is slightly shifted to the blue because of the 5D<sub>4</sub> to 7F<sub>6</sub> transition at 490 nm.

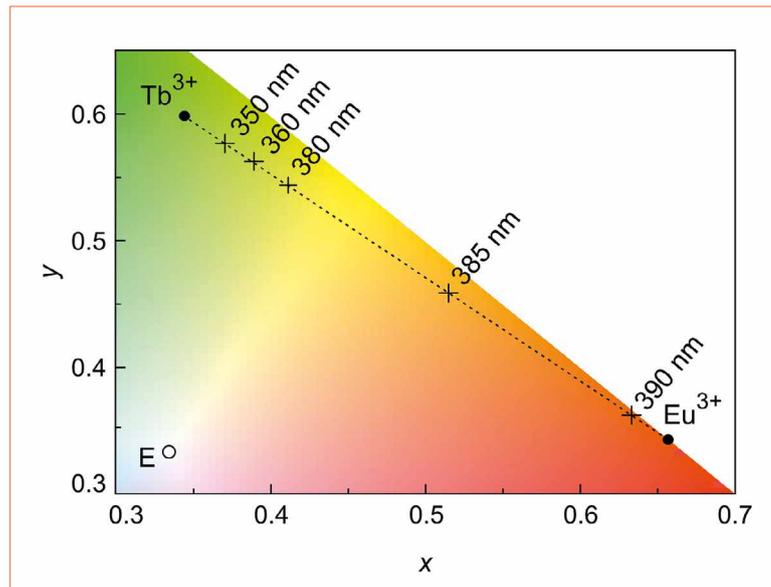
The emission spectra of the double-doped glasses depend significantly on the RE ion concentration (Figure 4). The color coordinate of the  $\text{Eu}^{3+}$  /  $\text{Tb}^{3+}$  double-doped glass shifts from the green ( $\text{Tb}^{3+}$ ) to the red ( $\text{Eu}^{3+}$ ) spectral range with increasing  $\text{Eu}^{3+}$  concentration. The dashed line connecting the color coordinates of the  $\text{Eu}^{3+}$  and  $\text{Tb}^{3+}$  single-doped glasses indicates all possible color coordinates of the double-doped glass. Note that the emission spectrum of the equally double-doped glass (see 0.5 at.%  $\text{Eu}^{3+}$  / 0.5 at.%  $\text{Tb}^{3+}$  in Figure 4) is shifted to the red spectral range since there is a significant energy transfer from  $\text{Tb}^{3+}$  to  $\text{Eu}^{3+}$  [15, 30]. The dotted lines going through the point of equal energy, E, indicate the complementary blue region. This method of color mixing by varying the RE ratio is a conventional method, in particular used for white LED phosphors. However, the color of the phosphor is then fixed and cannot be changed during use.

In addition to the above-described color mixing by changing the RE doping concentration, double-doped borate glass offers the opportunity to vary the color coordinates upon changing the excitation wavelength accordingly. This is shown in Figure 5 for the 0.05 at.%  $\text{Eu}^{3+}$  / 0.5 at.%  $\text{Tb}^{3+}$  doped glass. For UV excitation at 350 nm, the  $\text{Tb}^{3+}$  emission dominates the spectrum resulting in a green color appearance, while 380 nm excitation leads to a yellow one. Excitation at 385 nm and 390 nm results in an orange and red color impression, respectively, due to the strong  $\text{Eu}^{3+}$  absorption bands at these wavelengths. A color change during use is thus possible. Changing the excitation wavelength, e.g. from 350 nm to 390 nm, the color coordinates switch from green to red.

Using different excitation wavelengths enables an immediate change in color coordinates with one phosphor. This method might be used in control lamps to attract attention or in lighting applications where a change in color coordinates during use is wanted.

### Conclusion

$\text{Eu}^{3+}$  /  $\text{Tb}^{3+}$  double-doped borate glass has been investigated for its potential as a photon converter for use in white LEDs. With the  $\text{Tb}^{3+}$  emission in the green and the  $\text{Eu}^{3+}$  emission in the red spectral range, color mixing from green to red is enabled by varying the ratio of the RE doping level accordingly. In addition, using different excitation wavelengths can also vary the color coordinates of the phosphor.



**Figure 5:** Section of the CIE color space chromaticity diagram with point of equal energy, E, and the color coordinates of the 0.05 at.%  $\text{Eu}^{3+}$  / 0.5 at.%  $\text{Tb}^{3+}$  doped borate glass for different excitation wavelengths (crosses) between the color coordinates of the single-doped glasses (full dots)

Switching between different excitation wavelengths enables a fast change in color coordinates from green to yellow then to red.

Moreover, the investigated glasses provide good temperature stability in the temperature range investigated. ■

### Acknowledgements:

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# Potting Processes as a Part of LED-Based Lighting Module Manufacturing Methods

Many manufacturing processes need very accurate dosing. One such dosing process concerns the potting of LED-modules. Numerous parameters affect the potting quality. Willi Huber from the Business Unit Adhesives & Chemicals at ViscoTec Pumpen- u. Dosiertechnik GmbH explains casting equipment, critical parameters and appropriate potting methods.

The specific objective of the potting of LED-modules is to protect the unit against environmental influences. The goal is to encapsulate the functional area for stable operating conditions. Surrounding factors which may affect the functionality or lifetime of the LED-assemblies and which need to be kept away are humidity, water (spray, condensation), oils/oil mist, chemicals, environment dirt, weathering, dust or mechanical stress from the outside. The protective function of LED modules using the potting approach is realized through the so-called casting compounds, of which there are a large variety.

## Short Introduction to Common Potting Concepts

Fully potted with complete encapsulation of a module: The potting level is above upper component level.

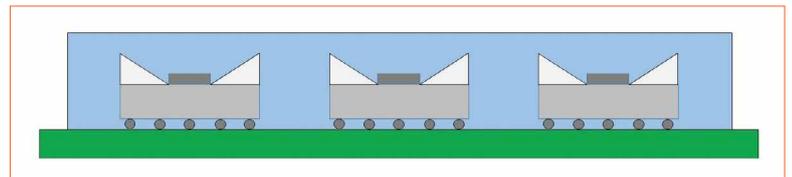


Figure 1: Complete module encapsulation

Partially potted with partial encapsulation of a module: The potting level is between lower and upper component level:

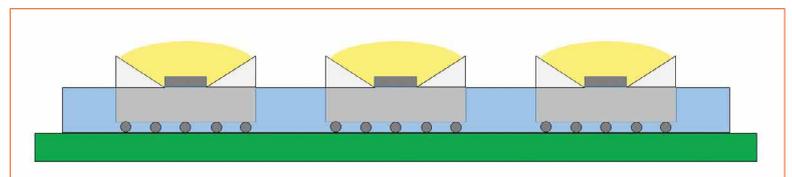


Figure 2: Partial module encapsulation

Selective encapsulation: Only a section/partial area of a module is encapsulated above the upper component level.

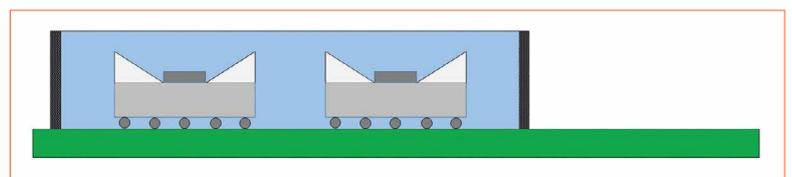


Figure 3: Selective encapsulation

Potting compounds are applied in viscous consistency and cure to definable hardness values according to the set hardness mechanism. Potting materials are available in 1-component as well as 2-component types.

There is a significant number of process parameters that can influence the quality of a potting process in terms of a repeatable unit production. As a major aspect, the dosing volumes are relatively large in relation to the component or module size. The nature of a potting process is to fill a module completely with compound compared to bonding applications with dot or bead dosing shapes and related smaller dosing volumes. Consequently, LED-potting processes generate two basic requirements with respect to the process design.

#### Two basic requirements to the LED-potting process design:

- High precision of a selected dosing system to keep the accuracy in the full range up to high dosing volumes
- High material flow rates in order to keep acceptable cycle times for the production set-up

### Potting Applications Realized by Industrial Production Processes

The process can be realized, in general, by two different process concepts. They come along with significant differences in their system configurations of the potting cell.

Process concept number one concerns the so-called atmospheric casting concept, also referred to as open casting concept.

The reconstituted casting compound is introduced at atmospheric pressure from top into the LED-module (casting mold), using the force of gravity. Alternatively, it can be applied upward from the module bottom side by a respective dosing pressure. Appropriate dosing systems are capable of generating so-called dosing profiles, by means of which the molding process is controlled by varying flow rates and activation times. Dosing profiles help to control the compound flow with the result of reduction of air pockets on encapsulated LED-modules. Air pockets on unprocessed units can also be eliminated before or during the atmospheric casting process by



**Figure 4:**  
Buffer container of material conditioning systems

further measures. Effective methods are suitable component designs (avoidance of dead space areas) or a well-chosen component position (e.g. skew) during the potting sequence.

In case the atmospheric casting approach cannot guarantee a bubble-free process, the alternative is the switch to a vacuum based potting technology. In this method, an assembly is cast in a vacuum chamber under process vacuum down to a few mbar. In particular, enclosed air pockets at an assembly, which cannot be edged out during atmospheric potting, are removed (sucked-put) by the evacuation step of the process. But this article will only consider the atmospheric casting as a common concept for encapsulating of LED-assemblies.

### System Technologies of Casting Equipment

This section introduces dosing technology for industrial, fully automated potting lines only. A potting cell within a process environment for industrial volume production includes a material supply unit, a material conditioning system and the dispensing unit. Handling systems (automation systems) are required in addition, in case of automated component handling. The following chapters describe the system components of the dosing unit (without the handling equipment) in detail and highlight the relevant influencing variables for an optimized process design.

### Material supply system

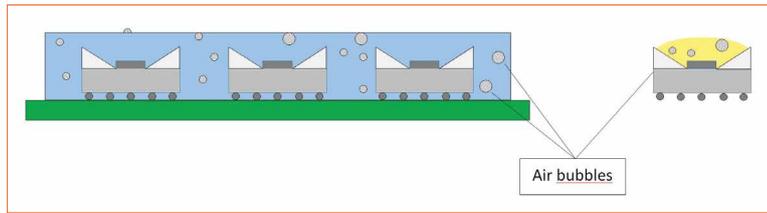
Potting materials are generally self-leveling fluids. They can be filled into storage containers manually, transferred into a storage tank by a vacuum system and suction lance or can be handled by a bin emptying device/pump. Pressure vessel systems increase the risk of air injection into the fluid and do not offer significant process advantages. The requirement of batch handling of filled materials in order to keep the ratio liquid and filler is a minor aspect of LED-casting applications. Casting compounds for LED-products are quite limited in terms of filling components due to the required optical material properties. 2-component casting system configurations require a duplication of the system components in order to handle the respective A/B material components.

### Material treatment systems

The material conditioning technology represents an essential process area for the composition of reliable production processes within potting cells. The material treatment system implements the functionality of material buffer, material conditioning and material feed to the downstream dosing system. The material buffer function is realized by a buffer container/tank that includes the functional components for the material conditioning process as well.

The storage tank can be filled manually by the operator or

**Figure 5:**  
Air bubbles in non-degassed casting compounds



automatically using a vacuum system and suction lance. Filled casting materials require a transfer of the entire container volume into the buffer container at once in order to keep the mixing ratio of fluid and filler. The lower fluid level monitoring/display ("refilling necessary") is usually carried out by the system itself. For manual filling, the compliance with the upper filling level ("container full") must be controlled by the operator itself. The upper material filling level is monitored and controlled in contrary by the process monitoring system within an automatic process set-up. The material preparation technique is composed of the process steps stirring/homogenization, degassing, recirculation and temperature control.

The requirements of the individual process components are as follows:

#### **Stirring/homogenization:**

The stirring/homogenization process is to maintain a balanced distribution of the material components within the fluid and thus to ensure the material homogeneity and properties. The requirement for this process step is given due to the separation behavior of fluids. The effect of material separation of dispensed materials is reinforced by the tendency to lower viscosity of casting compounds. A homogenization step is also required in case the compounds with a strong tendency for material separation are transferred into the fluid buffer without a prior mixing process inside the delivery container. Otherwise, the homogeneity and correct distribution of the ingredients of the material is given only in the case that the entire container/batch volume is transferred into the buffer at once.

#### **Material degassing:**

The approach of material degassing ensures that the applied casting material is free of air bubbles. The presence of air bubbles in finished assemblies or module sections can lead to a significant reduction of the functionality or product lifetime; in the worst cases, even to an overall product failure. It should be referred to the fact again, that module encapsulation is considered here in the context of a protective function and that this function is no longer given with air inclusions. Equal critical for LED-modules is the major reduction of the optical quality of casted units caused by air bubbles.

Process and product quality are only ensured of absolutely properly conditioned material. Multiple, strong requirements are combined with the quality of the degassing process.

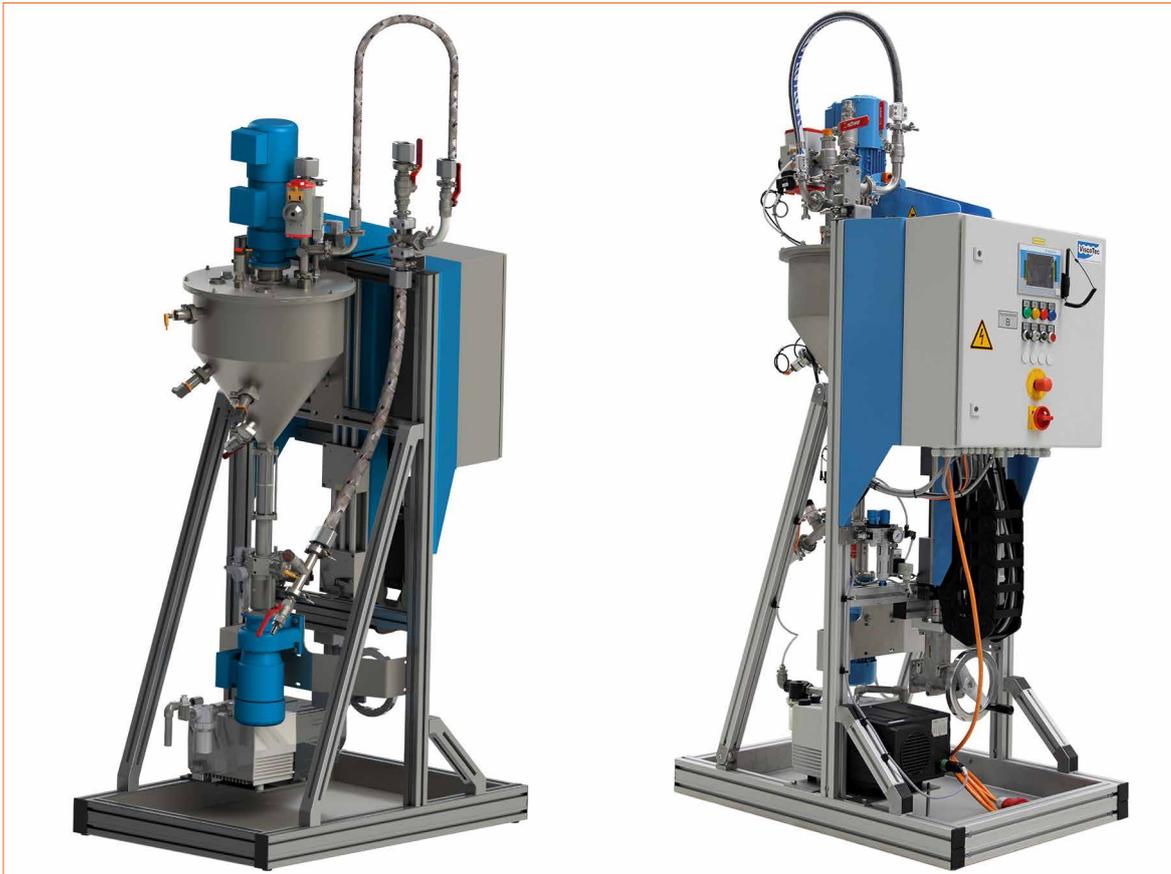
#### **Requirements to support the quality of the degassing process:**

- The level of the process vacuum must be sufficient in order to ensure the functionality and quality of the degassing process
- In the case of a vacuum casting approach it is required that the level of the degassing vacuum is lower than the level of the chamber vacuum of the potting cell. Otherwise the casting material would be exposed to an additional degassing process in the potting vacuum chamber
- The process vacuum cannot generally be set low without any limitations. There is a risk to remove gaseous constituents from the fluid at a too low degassing vacuum level. The vacuum level is to be kept reliable by the equipment in a narrow process window

The majority of material conditioning systems is based on the concept of batch processing. These systems can be used as single process system with one process chamber or as a dual process system with the need for two process chambers. The single process system handles the process steps material filling, conditioning and material feed sequentially. The system is not available for material supply during the filling/degassing process and vice versa. Dual process systems are capable for material filling/conditioning in one process chamber while the second process chamber supplies the dosing station with pre-prepared compound in parallel. However, these systems require two separate process chambers with doubled efforts for system components and system maintenance.

However, these limitations can be eliminated by a full in-line processing system. This system provides an in-line process, in which the functions of material filling, material stirring/homogenization, especially the degassing process and then material feed towards a downstream dosing unit can be realized in a fully parallel, continuous process with a single process chamber only.

The process chamber is continuously operated in a vacuum mode. The individually required vacuum level per each casting material type can be defined within the software-based system configuration and is controlled precisely via the system control unit to this predetermined value. Vacuum fluctuations are suppressed and a stable chamber vacuum is given. The achievement of the necessary level of degassing vacuum is ensured; this also allows complying with vacuum maximum values in order to eliminate the change of material properties in case of exceeding such maximum values. The material transfer from the delivery container into the process chamber can be arranged under the use of the chamber vacuum (via suction lance) in parallel



**Figure 6:**  
In-line process material conditioning systems

to the homogenization and degassing process. The filling process is started and stopped automatically for a fully filled chamber via material level sensors. Adequate valve technology precisely controls the compliance with the process parameters.

Besides a continuous material degassing method in particular, the introduced in-line process technology allows the additional, parallel take-out of material from the evacuated process chamber down to lowest vacuum levels. Already degassed casting material can be taken-out for the supply of the dosing station simultaneously with the ongoing evacuation process. This method offers considerable advantages for system users. A continuous production process can be achieved with the in-line technology with only one system/ process chamber in contrary to batch systems with the required number of two process units/ chambers. The material preparation process is entirely software controlled. Filling, homogenization, degassing and material supply are

realized in a continuous process. Process continuity raises the process quality to higher levels. In addition, the elimination of recurring evacuation and ventilation cycles as of a batch process type reduces the amount of injected humidity into the process chamber.

#### **Recirculation:**

The recirculation of fluids ensures that material properties of the material to be supplied to a casting station inside tubes/hoses are kept in line with the process requirements. Such material can stay in hoses over a prolonged period sometimes (system down times, weekend break) and thereby may change its properties. This includes, for example, separation or cooling effects of pre-heated material. Recirculation redirects the material flow back into the purification system, where the material will be processed again to its required conditions.

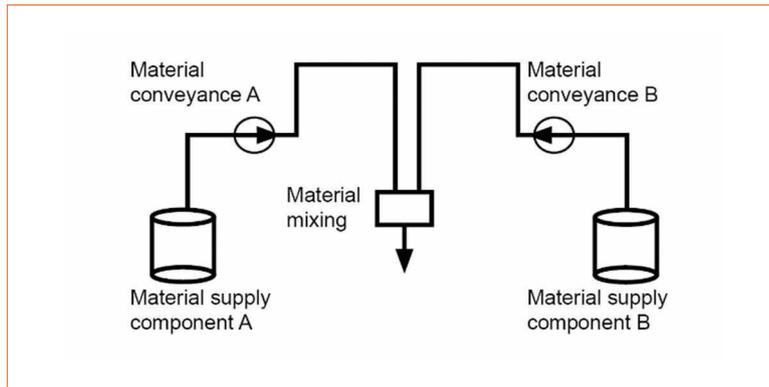
#### **Temperature control:**

The temperature control of casting materials is used to align their material conditions with regards to

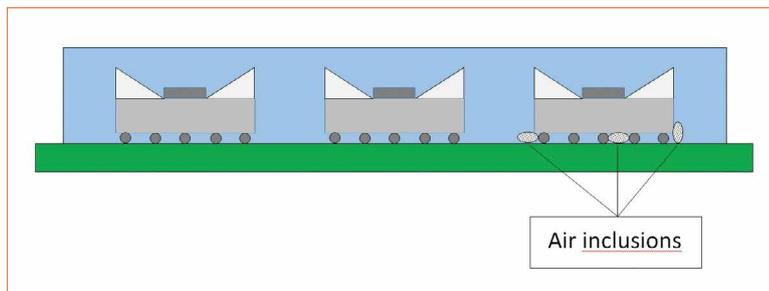
an optimized production process for casting applications. Pre-heating of the casting compound mainly reduces their viscosity, thus achieving an improved flow behavior and degassing quality. In addition, process variations by changing ambient temperatures can be eliminated throughout the stable fluid temperature. Adverse effects of fluid temperature increase are accelerated separation processes (of medium and fillers) and reduced reaction times (e.g. reduced pot life) of the casting compound. The adverse approach of material cooling is also a part of temperature control in order to stabilize a production process.

A recirculation path is essential in order re-heat or re-cool material back to the set- temperature if the tempering step is performed locally at the treatment system only. Alternatively, a complete heating/ cooling line can be realized from the material preparation system, via the supply hoses, manifolds etc. all the way up to the connected dispensing unit. The material supply path needs to be realized as defined for one

**Figure 7:**  
System configuration  
for a 2-component  
casting set-up



**Figure 8:**  
Undesired air  
inclusions at an LED-  
module can affect  
thermal performance



time for a 1-component potting process. For 2-component applications the path for material transfer from the delivery container, material conditioning and material feed is to be implemented in duplicate for component A and component B.

**Dosing system:**

First of all, the selected casting compound generally defines whether the dosing process has to be based on a 1-component or a 2-component system configuration. Notwithstanding this basic system configuration, the same rules apply for the technical and quality requirements for the dosing systems for both - 1-component as well as 2-component potting processes.

Casting processes are coming along with rather larger dosing volumes, especially at fully encapsulated modules. Despite these larger dosing volumes, there is the need to keep the dosing precisions on high accuracy levels. The casting process requires a match with the defined filling levels as an essential aspect for the final product functionality and product quality. The demand for surpassing dosing precisions is based on the fact that any system inaccuracy is scaled upward with increasing dosing

volumes, so that in absolute terms large dosing volumes could result in significant overall inaccuracies. The selection needs to be for dosing concepts that can be over a high linearity over a wide range of dosing volumes and also a high reproducibility of such dispensing precisions.

A special task along with potting applications is the ability of dosing technologies to implement so-called dosing profiles. As identified previously, inclusion of air chambers in the casting compound can be reduced, for example, by a vacuum casting method. However, vacuum casting demands an extended system configuration and additional equipment parts compared to atmospheric casting. The objective is therefore to realize casting applications as much as possible under atmospheric pressure.

An essential requirement on dosing systems in this case is the ability to work with dosing profiles. This means that the material flow of the casting compound needs to be controlled in a way that will prevent the injection of air chambers from outside or to even eliminate (push out) existing air chambers at the LED-module. Technically, dosing profiles allow the control of flow

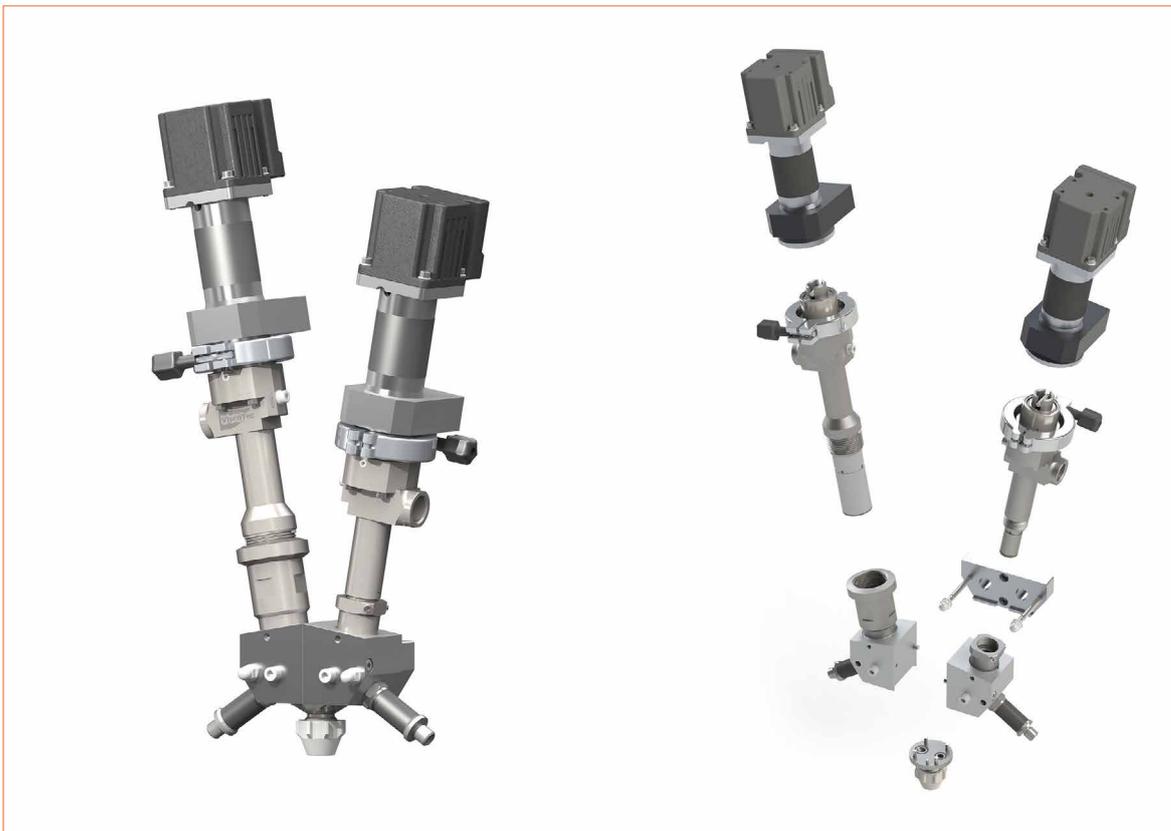
rates and start-stop sequences. Dosing profiles in combination with aligned handling/robot units allow the creation of material flows in one predefined direction and to consequently fill module sections from one direction only. The approach is capable of pushing out existing air pockets at the assembly and eliminating the generation of cavities in parallel.

The key aspect for this purpose is the ability of the dynamic operation/control of dosing systems. This feature refers to the possibility of a dosing system to dynamically adapt the dosing flow rate during the potting cycle. If the process requires, for example, a low flow rate at one point in the potting process in order to achieve a certain flow behavior, such a dynamic dosing operation allows for the reduction of the dosing speed within the process sequence. If a high flow rate is required in another process stage the dosing speed can be increased dynamically in the potting cycle. The dynamic adjustment of the material flow rate can only be realized by high end dosing technologies which are capable of ultimately keeping the high dosing accuracies in such a dynamic operation mode at any time.

Excellent conditions for dosing applications in the area of LED-module encapsulation are given by the endless piston technology used by ViscoTec as the preferred dosing technology. The dosing units are characterized through a volumetrically absolutely precise dosing principle, providing highest and reliable dosing accuracies independent of the material viscosity. The special arrangement of a rotor and a stator unit each provides so-called closed dosing chambers with absolutely identical chamber volumes, which do not change during the dosing process. Steady chamber volumes directly result in identical, repeatable dosing volumes. This enhanced pump geometry guarantees a pulsation free material flow. The rotor/stator combination already creates a



**Figure 9:**  
Sealing line on  
dispensing pump  
with endless piston  
technology



**Figure 10:**  
2-component mixing  
head from ViscoTec

sealing line inside the pump (closed chambers) and thus represents a valveless dosing principle.

The dosing volume per rotor revolution is defined by the chamber volume: A full turn of the rotor applies the volume of one filled dosing chamber. In logical consequence, a change of the rotor speed causes an immediate and linear change of material flow rate. In fact, the flow rate is controlled proportionally to the speed of the drive unit and infinitely adjustable under the use of appropriate drive

units. The introduced dosing principle is well suited under these technical conditions for the dynamic control of the material flow rates for the use of flow profiles in LED-potting applications.

The endless piston technology allows the realization of both - 1-component as well as 2-component dosing applications: Two 1-component dosing pumps are arranged side by side and connected via the mixing head segment for the configuration of a 2-component mixing and dispensing

unit. Material components A and B (2-component casting compounds consist of the resin and a hardener) are supplied separated from each other by two divided material channels by dead space optimized architecture towards the mixing head and static mixer unit. A special design of the outlet of the mixing head extends the separated material flow of component A and B into the static mixing tube and eliminates a mixing and curing reaction of the casting compound inside the mixing head itself.

The direct merge of the dosing pumps at the mixing head and the aligned realization of shortest channel lengths reduce potential dosing inaccuracies caused by long supply lines and resulting uncontrolled pressure profiles down to a minimum. The predetermined mixing ratios can be guaranteed on high accuracies with the highlighted system architecture.

The mixing principles of 2-component fluids are separated into static, static-dynamic and dynamic mixing. The static mixer process is based on the multiple re-layering of the flowing components by their repeated deflection as they flow through the mixing tube. Static mixers are structural elements of specially formed, rigid mixing element rows in

tubular bodies. A good static mixing quality is given with the typical low material viscosities of casting compounds, in general. The advantages of the static mixing process lie in the simple structure and lighter weight of the mixing unit. With the dynamic mixing principle the material components are fed into a mixing chamber and are mixed actively by an agitator. In contrast to the static mixing tube, the dynamic mixer must be cleaned after dosing. An implementation on a robot system is eventually limited by the weight of the dynamic mixing unit. Finally, the static-dynamic mixing concept reflects a mixer concept where the mixing elements of a static mixer-like mixing unit can be rotated inside the mixing tube by an external drive unit.

## Conclusions

Potting has a great influence of the final product quality, especially in respect to lifetime and reliability, but also efficiency. A number of decisions have to be made to choose the right potting material for an application and the appropriate dosing equipment. Accurate control of the different process parameters is inevitable. One of the biggest misjudgments would be to think that with larger dosing volumes accuracy would become less important. Dosing profiles and dynamic operation aligned with the robot units are key functionalities for a high quality production process. The endless piston technology offers the best preconditions for 1-component as well as 2-component dosing applications and is very flexible in its application. ■

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# Cost and Performance Optimization of Thermal Management Solution for High Power LEDs

The LED industry has a challenge. General lighting requires very bright LEDs that can replace incandescent and halogen lights. Manufacturers need efficacy, cost and manufacturability to be “just right” but most leading solutions, especially in thermal management, are short of the mark. Giles Humpston, applications engineer, Cambridge Nanotherm, discusses ways to combine performance with reasonable costs and good manufacturability.

The LED industry is being challenged. General lighting is where growth is, particularly in the retrofit and automotive markets, and what those markets require is very bright LEDs that can replace incandescent and halogen lights.

There are a number of ways to achieve this, and one of the most ubiquitous is using high-brightness packaged LEDs (HB LEDs). Whilst the lines are blurred, and changing as technologies develop, generally any LED over 1 W can be considered high-brightness.

As LEDs get brighter they also get hotter, so within these packages there will be some form of thermal management designed to conduct the heat away from the die as quickly as possible. Without adequate thermal management the life of the LED is significantly limited - not good when longevity is a key selling point of a product.

## The Challenges

The major LED manufacturers continue to push the boundaries by producing larger and brighter LED die ( $>1 \text{ mm}^2$ ). The question is how to package these to meet the demands of the industry. Traditional leadframe packaging (albeit often with new materials) are a popular choice and essentially offer a direct copper connection to the LED die, producing a very thermally effective and cheap solution.

However there are a couple of issues that rule out leadframes in many HB LED packaging applications. Notably there's a significant thermo-mechanical mismatch between the leadframe and the die (CTE and Young's modulus) that can have a significant impact on the reliability of the device. Also, the package size is (relatively) large ( $>20 \text{ mm}^2$ ).

As a result, the industry is increasingly looking to alternative options like ceramic substrates to package their HB LEDs.

## The Requirements

There are a number of requirements that a substrate must meet to be used for LED packaging.

The precision of the circuit needs to be very high. This limits the circuitization process to thin-film direct plated copper (DPC) processes rather than conventional thick-film reductive processes. Generally most HB LED package substrates have the copper tracks sputtered in place as this ensures the tracks are as even as possible (the copper is built up at a  $90^\circ$  angle to the board). This means that the track and gap specification can be much tighter ( $75 \mu\text{m}$  and  $50 \mu\text{m}$  respectively for  $75 \mu\text{m}$  copper) - a critical factor when contacts are required for multiple die and your total circuit size is less than  $10 \text{ mm}^2$ . The requirement for thin-film processing limits the range of materials that can be used - generally excluding any type of metal material that has a polymer dielectric layer.

Packaging substrates require through-hole connections that connect the two sides of the circuit together. These are filled with copper during the thin-film processing, so need to be electrically isolated from the rest of the substrate, and have a very small diameter (as small as 130  $\mu\text{m}$  for laser-drilled holes) to speed manufacture. This significantly limits the range of substrates that can be used (standard metal core PCBs fall down again at this point as it's a very expensive process to create isolated through-holes). These through-holes are also used as thermal vias to help improve the thermal performance of the substrate (copper being a fantastic conductor).

The substrate itself needs to be thermally conductive enough to remove the heat from the LED die to ensure it doesn't overheat. Here, there is a critical balance between cost and performance.

The substrate price correlates closely with its thermal conductivity; as thermal performance increases so does the cost. In an ideal world the material's performance would be 'just good enough' and the price would reflect this, providing the most cost-effective option within the specified window of thermal performance. The material also needs to be electrically isolating, although as packaged LEDs are not connected directly to mains power this generally only needs to be a maximum breakdown voltage of 500 V.

### The Current Commercial Options

Currently two materials make up the vast majority of HB LED substrates;  $\text{Al}_2\text{O}_3$  (alumina) and  $\text{AlN}$  (aluminium nitride). These two related materials are both from the advanced ceramics family and are used throughout the electronics industry. There are other alternatives that are coming to market and these will be dealt with later in this article.

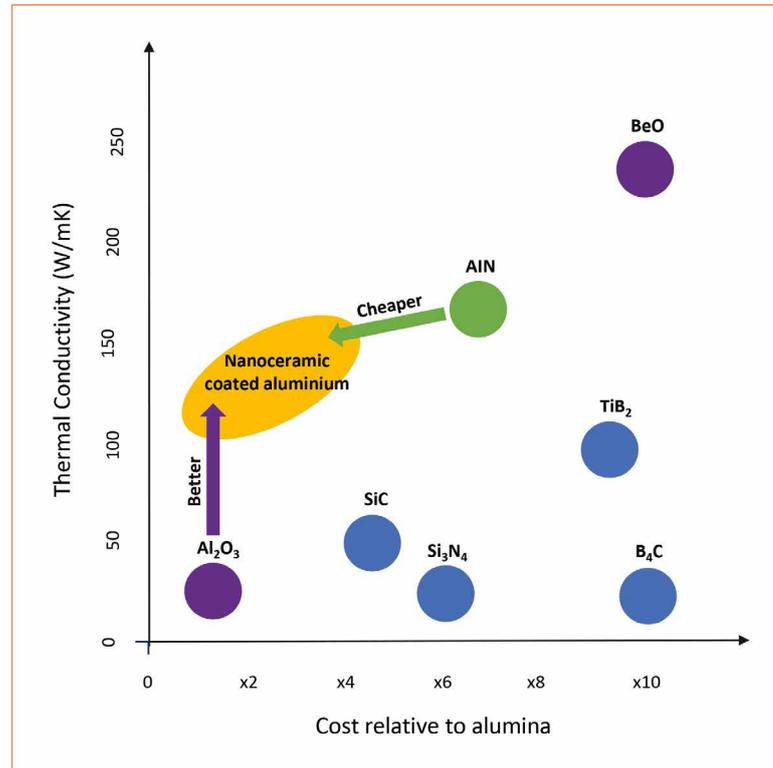


Figure 1: Performance and price of technical ceramics

Core to the use of ceramics is that they tick all of the requirements: They are thermally effective, electrically isolating, drillable, and capable of going through thin-film processing.

$\text{Al}_2\text{O}_3$  (alumina, or aluminium oxide) is a chemical compound of aluminium and oxygen. It's a naturally occurring material and is used to produce aluminium metal, as an abrasive, as a refractory material and as a substrate for electronics. Depending on purity  $\text{Al}_2\text{O}_3$  offers a thermal conductivity of between 20-30 W/mK (and sometimes a little more or less). This makes it an acceptable material for HB LEDs. But only just. The key driver with  $\text{Al}_2\text{O}_3$  is the cost - it's a relatively affordable option, particularly when compared to the alternative; its cousin aluminium nitride.

$\text{AlN}$  (aluminium nitride) is a synthesized material that is used almost exclusively in the electronics industry. Much like  $\text{Al}_2\text{O}_3$  it is an excellent dielectric, but unlike  $\text{Al}_2\text{O}_3$  it is thermally an excellent conductor with a performance (depending on purity) in the region of 140-180 W/mK. However due to the exceptionally

high temperatures required to process  $\text{AlN}$  it is also very expensive.

The industry is crying out for a product that sits between these two materials, one that is 'just right' and not too extreme - not too high in thermal performance or too low, not too high a price or too low. This is the sweet spot: a material that provides the 'just right' thermal performance between  $\text{Al}_2\text{O}_3$  and  $\text{AlN}$  at an intermediate price (Figure 1).

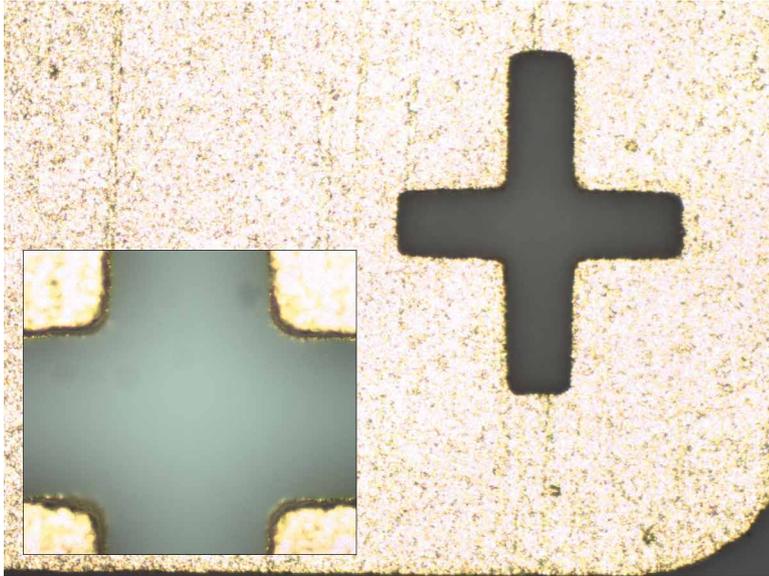
### Trial and Error

The first question that comes to mind is why isn't there a solution to fill this gap? If this is such a big issue surely it would have been addressed by now. The answer is that there have been many attempts.

MCPCBs (metal core PCBs) are sheets of metal such as aluminium or copper coated with a ceramic-infused epoxy dielectric layer. They come in at a composite thermal conductivity of anywhere up to 100 W/mK and cost a fraction of the price of  $\text{Al}_2\text{O}_3$ . On first appearance this makes MCPCBs a good candidate. Unfortunately MCPCBs cannot have electrically isolated through-holes or vias

**Figure2:**

A 10x close up of a circuit feature made using a thin film process with an electroless nickel immersion gold (ENIG) surface finish. The gap width on this type of feature is typically 75µm. The inset shows a 50x close up of the same thin film substrate that demonstrates the extremely high tolerance achieved



(at least not within a sensible price range). Equally these PCBs are unsuitable for thin-film processing and use thick-film reductive processes to fabricate circuits - way off the fine tolerances required by packaged LEDs. The epoxy also limits the maximum sustained operating temperature of the PCBs and it has a glass transition temperature that gives rise to a number of failure modes.

Si (silicon) is another much touted option. Weighing in at 150 W/mK, it offers good thermal conductivity and there is the entire semiconductor industry infrastructure available with a plethora of established processes available for metallizing it and fabricating vias. But silicon sheets are only available as round wafers, not the rectangular tile formats used in the LED industry. Silicon, like alumina and aluminium nitride, is also quite brittle which results in losses during manufacture and limits the mechanical mounting methods that can be used. Using bolts to fasten down a silicon substrate is not an endeavour for the faint-hearted! Finally there is cost. There is so much demand for high purity silicon from the semiconductor industry that no one bothers to make cheap substrate material. What you can buy is way over specified for LEDs, and this is reflected in the price tag. Similarly most off-the shelf

equipment for processing silicon wafers is designed to specifications far beyond what is required and virtually every bit of kit seems to have a price tag north of \$1M.

BeO (beryllium oxide), also known as beryllia, is another contender. It's an effective electrical conductor with a higher thermal conductivity than any other non-metal except diamond. Thermally it actually exceeds most metals. In theory BeO is the perfect material; in practice it's ridiculously expensive and in dust form is carcinogenic and may cause chronic Berylliosis.

There are also a number of companies, large and small, offering innovative 'mechanical' solutions to the problem. Generally these have low adoption because either the design is specific to a given LED die, or it requires the LED to have internal dielectric isolation of its thermal pad.

AlN is an expensive option for a number of reasons: The raw powder is expensive and it undergoes costly non-aqueous processing. It also requires a separate binder removal process; a batch sintering cycle, and a batch flat fire cycle.

There are developments underway to drive down the cost by using a spray drying process, where molten aluminium is sprayed into a nitrogen atmosphere where it reacts to form

AlN powder. This has an impact on the performance as well as the price - producing an AlN substrate that comes in a 100 W/mK.

Another prospect is low-temperature sintering of AlN using additives to reduce the temperature and hence process costs. Current endeavour allows the material to densify at 1675°C - 1690°C as compared to 1820°C - 1835°C. Its properties are very similar to traditional AlN except that the thermal conductivity is around the bottom end of performance. Thus far, neither of these low cost variants of AlN have entered the high volume commercial market.

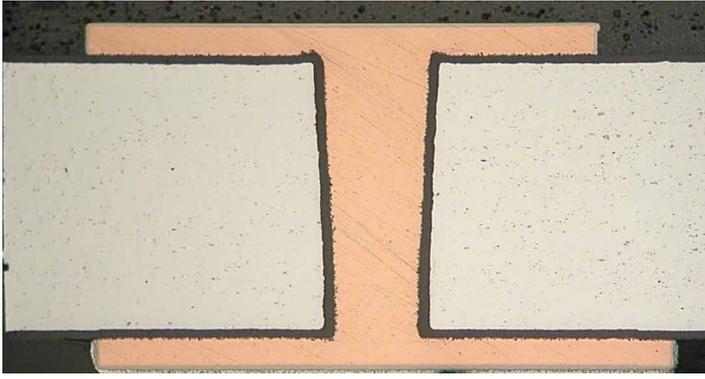
### The 'Just Right' Solution

This still leaves a gaping hole in the market between Al<sub>2</sub>O<sub>3</sub> and AlN and this is where many are touting an innovative new approach to this problem; nanoceramic.

The new unique material with a composite thermal conductivity of 152 W/mK - perfectly meets all but the most extreme HB LED requirements.

This material is created using a patented Electro Chemical Oxidation (ECO) process that converts the surface of standard grade aluminium into an exceptionally thin (nanoscale) layer of Al<sub>2</sub>O<sub>3</sub> measuring no more than a few microns thick. The Al<sub>2</sub>O<sub>3</sub> surface forms an integral part of the aluminium so there's a perfect connection between the different materials. This means heat will conduct fast and easily, whilst the Al<sub>2</sub>O<sub>3</sub> can be grown to exactly the right thickness to match the breakdown voltage requirements of the HB LED (Figure 2).

The aqueous electrochemical processes used in manufacture are cheap, particularly, as in this case, as the effluent is so benign that it can be discharged directly into the domestic sewer (with a permit from the relevant Utility company!). Thus the material costs are not much more than the base aluminium alloy sheet.



**Figure 3:** A cross section of a copper-filled via in a nanoceramic board. The dark lines between the orange copper and the light grey aluminium delineate the nanoscale layer of alumina acting as the dielectric layer

This material also overcomes the problem of many other solutions; the inability to provide through-holes. In this case the aluminium can be drilled (either by laser or mechanically) prior to the nanoceramic conversion process. This means that through-holes and vias will have exactly the same electrical isolation as the surface (Figure 3).

As the surface of this material is a ceramic ( $Al_2O_3$ ) it is suitable to be put through thin-film DPC processing, ensuring that the circuit has the tolerances needed for HB LED packaging.

With a composite thermal performance of 158 W/mK nanoceramic sits closer to AlN than  $Al_2O_3$  and its price reflects this. This makes nanoceramic the ideal choice for a wide range of HB LED packaging applications, offering the perfect balance of price and performance for all but the most thermally challenging applications.

And there are additional benefits to be had. Unlike brittle ceramics and silicon substrates, aluminium is tough. Nanoceramic, being a nanograin material, also has high fracture toughness. If necessity dictates nanoceramic-coated aluminium plates can even be bent without loss of dielectric isolation. More interestingly, nanoceramic-coated aluminium can be manufactured in huge tiles. The largest AlN tiles on the market today measure a mere 5x7 inches (125x175 mm). Aluminium plates can be purchased with dimensions in metres so can be made in sizes to suit the thin film process line, not the abilities of the ceramic tile manufacturer. Ultimately this means more circuits per tile, helping to bring some of the economies of scale enjoyed in PCB land to semiconductor processing.

## Conclusions

HB LEDs rely on ceramic substrates for their construction. The choice is limited to cheap alumina with poor thermal performance or very expensive aluminium nitride with exceptional thermal conductivity. Consequently there is huge demand for a new substrate material that has good thermal properties, competitive pricing and is compatible with the existing LED packaging infrastructure. Nanoceramic coated aluminium admirably meets this specification with the added benefit of being exceptionally tough so there are no yield losses due to breakage. Nanoceramic coated aluminium also offers the tantalising prospect of dramatically increasing the size of LED substrates to exploit the consequential economies of scale. ■

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# More Efficient Plant Growth with Quantum Dots

Using LEDs for plant growth lights is nothing new, nor is the use of QDs in LED lighting. While it is already proven that LED systems have big advantages over conventional plant lighting technologies, it is not common knowledge that Cd-free QDs are ideal candidates for optimizing the light spectrum for plant growth systems. Dale Needham, Business Development Director-Lighting at Nanoco Lighting, explains the opportunities and advantages based on Nanoco's proprietary and patent-protected CFQD® cadmium-free quantum dot LED grow lighting systems.

For plants to thrive, they require the full-spectrum light of the sun; chlorophyll in the foliage absorbs sunlight to provide energy for all of the plant's needs, while photosynthesis - using wavelengths between 400 and 700 nanometers (nm) - is the plant's process of converting light energy from the sun. Most plants do not need all of the color bands in the visible spectrum. For instance, flowering plants use the full spectrum of visible light, but some wavelengths are more important than others. Red light is crucial for hormone activation, which powers the flowering and fruiting processes, while blue light encourages the compact "bushy" appearance of healthy plant growth. For this reason, growers relying on artificial plant lighting such as LEDs concentrate on the blue and red parts of the spectrum.

Precise spectrum light, along with the intensity and duration of that light, simultaneously triggers plant flowering, growth, and reproduction, yet plants are quite selective in the light they use. Generally, their requirements are limited to small, specific bands of light, and they reject any additional

light that's not needed. This might suggest that sunlight is rather inefficient as a plant's energy source, but, due to its abundance of light energy, wastage is hardly noticed. In grow lighting environments,

however, the exact amount of lighting that's needed for plant growth must be provided artificially, while too much lighting can be harmful to plants, inefficient, and quite costly for vertical system farmers.

**Figure 1:**  
Lettuce growing under LED lighting



## Benefits of LED Lighting

LEDs provide particular benefits to the grow light and horticulture industries because, unlike traditional sources such as incandescent, fluorescent, halogen, or high intensity discharge lamps, they can be customized to encourage chlorophyll absorption in plants. By promoting healthy development through wavelength specificity and linear photon output, consuming far less energy, and casting less heat, LEDs are not only a cost-effective solution, but also improve the agriculturist's ability to control their growing environment. However, challenges exist in easily tailoring existing LED fixtures to meet direct specifications in color for plant variation and different stages of growth.

A new technology with unique optical qualities is poised to take on this challenge. Cadmium-free quantum dots enable emission wavelength precision that consistently produces the clear and concentrated color essential for vertical grow systems. Tuning the size of these brilliant nanoparticles makes it possible to tweak the light emitted from an LED system to any color in the spectrum, while maintaining the energy efficiency of the LED.

## Development of LED Grow Lighting

If growing potatoes to survive on Mars sounds like a science fiction plot, consider that much of the early research into LED grow lighting was conducted by scientists affiliated with the National Aeronautics and Space Administration (NASA). As early as the 1980s, researchers began to evaluate how LED lighting systems might ensure healthy plant growth in hostile conditions, and the impact this new technology could have on serious concerns such as drought, pestilence, and world hunger.

Since blue-emitting LEDs were not yet available, the earliest

experiments were limited to arrays of red LEDs. Research into industrial applications for LEDs accelerated during the 1990s, resulting in a stream of technological innovations that boosted luminous efficacy and increased the range of available colors to include blue, green, white, and more.

These developments are of tremendous benefit to scientists working in horticultural lighting, for whom LEDs represent "the first light source to have the capability of true spectral control, allowing wavelengths to be matched to plant photoreceptors to provide more optimal production and to influence plant morphology and composition." [1]

Greater spectral control is one of several advantages that LEDs maintain over traditional grow lighting systems. To achieve the ultimate spectrum for grow lighting, color temperature, measured using the Kelvin scale at a given wavelength, is one of the most important considerations. As a standard definition, the color temperature of a light source is the temperature of an ideal blackbody radiator that radiates light of comparable hue to that of the light source. The sun closely represents a blackbody radiator with a color temperature of about 5,900 K. Respectively, when discussing LEDs, colors above 5,000 K are known as cool blues and closely resemble natural sunlight, whereas colors below 3,000 K are known as warm reds.

In search of this ideal spectrum and most sufficient and efficient light source for indoor agriculture, the lighting market has evolved with various solutions triggering different responses from the plants - blue light inducing vegetative growth and red light inducing flowering. Some of these traditional grow lighting systems specialize in certain parts of the spectrum, while others span multiple wavelengths.

## All Present limitations

**Incandescent lighting**, though inexpensive to set up, can overheat plants, waste energy, and offers limited red and blue color necessary for vegetative cultivation and plant health.

**Halogen systems**, although very close to the spectrum of natural sunlight (6,000 K) and boasting a longer life span than incandescent lights (up to 15,000 hours) are also hampered by overheating and inefficiency. They can only provide light to a narrow area, ultimately burning or damaging plants by providing too much light to certain sections and not enough to others.

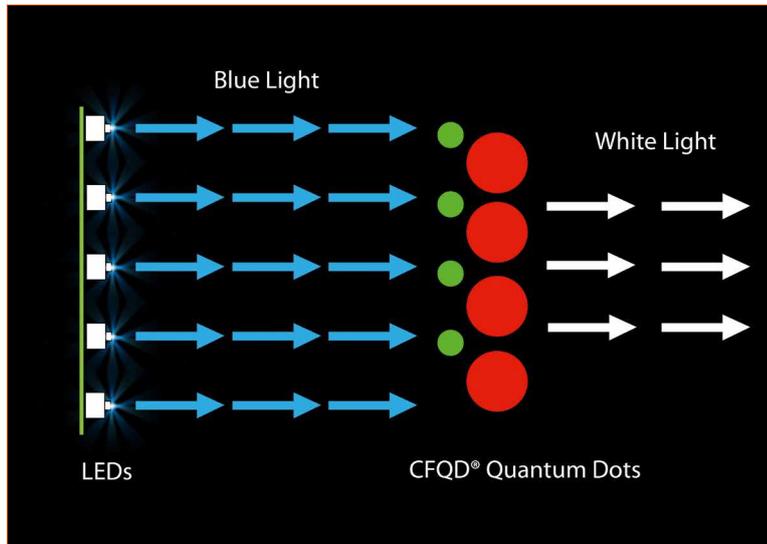
**Fluorescent grow lighting** is popular but tends to lack the red emissions essential for plant flowering. Full-spectrum fluorescent systems require specialized fixtures as part of their high upfront cost, deeming them inefficient.

**High-pressure sodium (HPS) and metal halide lamps** are examples of High Intensity Discharge (HIDs) lighting, a leader in the horticulture industry. Because HPS rigs produce light in the warm, red end of the spectrum, they are superior in flower production compared to metal halides or fluorescent lamps, but the plants appear washed out and nitrogen-starved due to the bulb's poor color rendering of cool, blue light. Further, two types of HPS must be combined in order to produce both red and blue light.

## LED Limitations

Fast forward to 2016. With the ability to produce the wavelengths of desired light at minimal heat production and exceedingly high-energy efficiency, LED lighting has quickly been adopted for indoor grow operations. While their popularity is increasing exponentially, LED grow systems still have limitations in their available emissions wavelengths, which can lead to less-than-optimum photon absorption for plant growth and, therefore, wasted energy.

**Figure 2:** Blue LEDs excite red and green cadmium-free quantum dots, resulting in high-quality white light



**Figure 3:** Grow light fixture with 3 array LED lamps with cadmium-free quantum dot film



This almost defeats the purpose of adopting LED technology for vertical farming endeavors.

Current grow systems utilize a combination of red and blue LEDs to stimulate chlorophyll absorption and supplement plant growth. However, this requires multiple SSL fixtures of differing wavelengths to achieve the various red, green, and blue emissions. A single LED with a red emission is not optimized for energy efficiency while only offering the warm light for specific plants and or reproductive stages. A strip light may have a combination of alternating red, red, blue, red, red, blue LED bulbs and so on. Yet, growers must move the light far enough from the plants for the color emissions to mix, so that each plant receives the correct ratio of blue to red; hence causing more energy output and inefficient light distribution.

The phosphors in standard LEDs are broad and vary in emission, which means that the plants do not receive the same spectra. While there is new narrow phosphor technology available on the market today, it is prohibitively expensive and built for display applications only. Since tolerance of the LED is large, the emission can shift and lack in replicating the desired light performance from luminaire to luminaire, which does nothing to maximize coverage over the absorption spectra.

Until recently, growers lacked the ability to precision-tune their LED systems required for different species of plants or growth stages. With the introduction of cadmium-free quantum dots, the next wave in LED-based grow lighting technology has arrived.

## Big Solution in a Tiny Package

Quantum dots are tiny fluorescent semiconductors -so small, you would need 10,000 to span the width of a human hair. If excited by an external light source, they absorb the energy and re-emit the light in a different color, depending on the size of the particle. When quantum dots were first introduced to the market, manufacturers immediately recognized their potential for enhancing LEDs in the lighting display category, where quantum dots, acting as a narrow band red phosphor, have a great advantage to give manufacturers excellent color quality (CRI, R9), without the large loss in efficiency they see with typical red phosphors.

Because cadmium-free quantum dots can be easily tuned to any color of the spectrum, they offer a breakthrough in grow lighting over traditional LED fixtures.

To date, most quantum dot technology, widely known for its use in the TV display market, contained cadmium, a toxic heavy metal that is highly regulated in the European Union. Due to the health and environmental threat that cadmium presents, the European Union's Restriction of Hazardous Substances Directive (RoHS) limits the amount of cadmium, lead, and mercury that can be included in electrical and electronic equipment sold in that market.

Heavy metal-free quantum dots are a fully RoHS-compliant option for manufacturers and consumers that provide all of the benefits associated with the technology in a safer and more sustainable product. They are available in custom sizes and shapes and are designed to work in conjunction with LEDs from 405 nm - 455 nm as required.

## LED Growing Made Greener

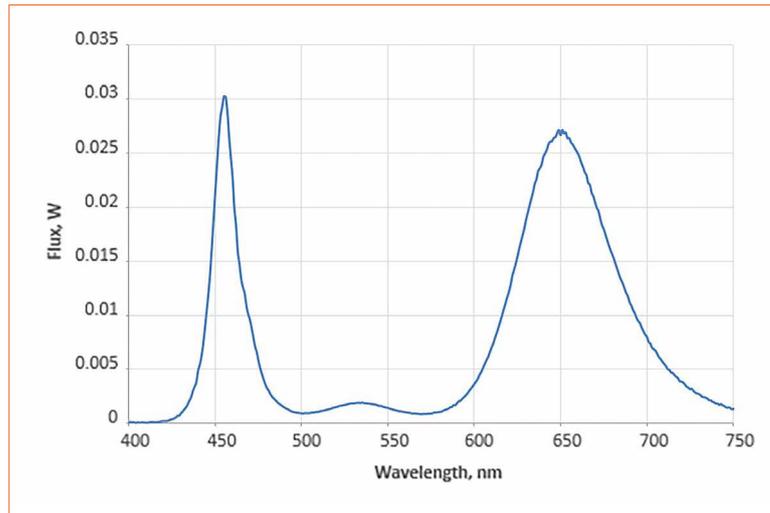
For horticultural lighting, cadmium-free quantum dot film is the optimal choice. These non-toxic, highly efficient materials can be easily

incorporated into various LED lighting formats to assist in the propagation and vegetative stage of plant growth. They can be manufactured in such a way that the blue-to-red emission ratio varies per film, which, again, is ideal for different species and stages of plant growth.

Traditional red and blue LED grow systems have the problem of diffusion, and therefore must be placed high above the plant so that the red and blue light illuminates the plants evenly. A LED system enhanced with cadmium-free quantum dot films can be easily tuned to the desired color of the spectrum. Because the emission originates from a single location, this reduces the cost associated with the increased circuitry of multiple SSL arrangements.

With cadmium-free quantum dots, the deep red emission of LED light can be tuned to stimulate optimal absorption of both type A and type B chlorophyll - important for crops such as basil and lettuce. By working with nature and permitting fine-tuning wavelengths to climate conditions and plant specifications, the technology ensures farmers have greater control over healthier and vibrant plant growth, such as creating a crisper or softer texture of lettuce.

Quantum dot films also provide excellent uniformity of light with much-reduced heat output compared to traditional sources, allowing the lights to be placed in closer proximity to the plants for maximum yield and plant quality, while saving space and energy. Uniformity also eliminates glare and hot spots from the growing environment. Growers can easily switch emission spectra by simply swapping the film while using the same LED module. This is a major advantage for farmers trying to maintain efficient indoor crops at low cost.



**Figure 4:** 1:1 ratio of blue to deep red cadmium-free quantum dot panel light

### Comparison: HPS vs. Cadmium-Free QD LED Grow Light

High Pressure Sodium (HPS) Lighting	LED/Cadmium-Free Quantum Dot Lighting
High energy consumption (Typically 150 W - 1,000 W)	Low energy consumption (Typically 10 W - 240 W)
Emits a broad range of colors; not optimized for plant growth	Only emits colors required to promote plant growth.
To deliver blue and red color for different stages of growth, farmers must combine HPS with metal halide lighting	Quantum dot film in the LED module is easily swapped to change emission spectra and can be precision-tuned to any color
Generates heat, which can damage growing plants	Little heat generation - can be positioned close to growing plants
Lifetime ~ 1 year	Guaranteed lifetime 3 years

**Table 1:** Comparison of HPS and the CFQD® cadmium-free quantum dot LED grow lighting systems

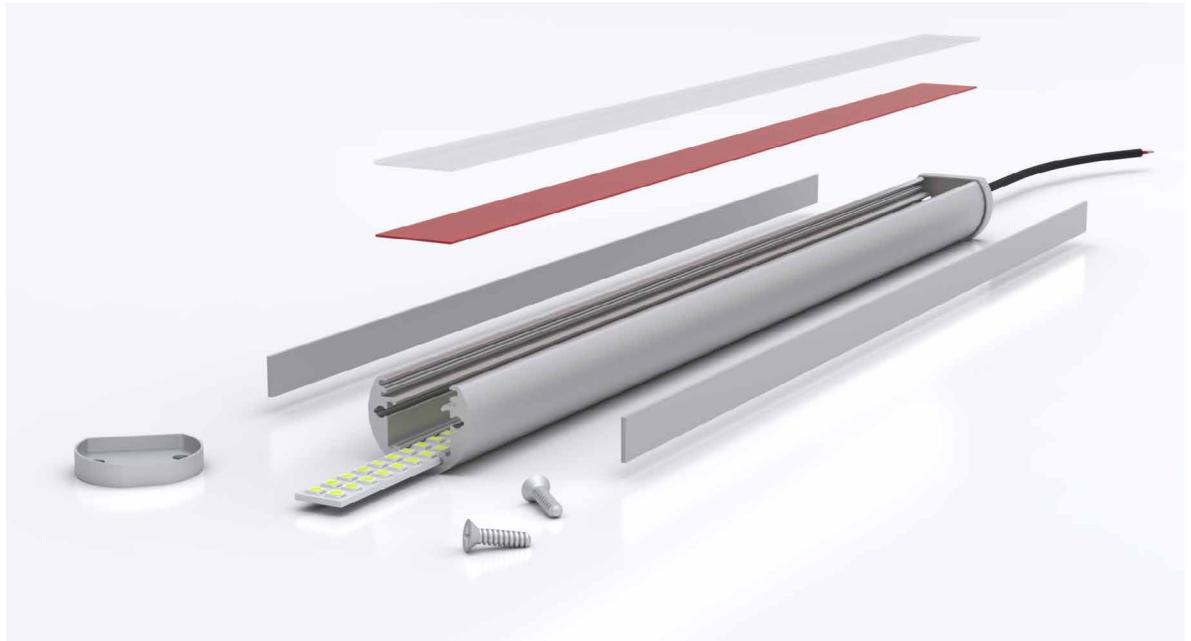
### Easy Integration into Existing LED Products

As the cadmium-free quantum dot film is the latest in lighting technologies, the materials have been developed to act as a platform technology, enabling all users to incorporate the film within their devices. With the correct concentration of blue light, users may manipulate their luminaire to emit the desired ratio of light at the deep red wavelength. Other spectra can be produced to the customers' individual requirements.

Using standard blue or UV LED components as the energy light source, cadmium-free quantum dot films are easily integrated into existing LED products, enabling the customization of individual color selection based on the particular plant or product being grown. The advantage of using film is that the quantum dots are broad absorbers; any blue LED from 430 to 460nm will excite the film. This offers a cost-effective and simple solution for manufacturers of horticulture lighting. Furthermore, using only blue LEDs as a light source greatly reduces the complexity of the light fixture, makes it easier to assemble, and enables manufactures to reduce stock holdings.

Cadmium-free quantum dot film typically slides into a groove within the LED light fitting (Figure 3) and sits about 2-5 cm away from the LEDs to allow for adequate mixing of the light.

**Figure 5:**  
CFQD® patent  
protected cadmium-  
free quantum dot deep  
red linear strip light



### A Growth Industry

With the vertical farming industry projected to reach USD 3.8 billion by 2020 [2], there is an urgent need for innovative technology to support this burgeoning global market. Driven by factors like year-round crop production in urban environments, pesticide-free high-quality fruits and vegetables,

and the power to control their growing climates, vertical farmers can benefit greatly from the unprecedented spectral precision of LED grow lighting enhanced with cadmium-free quantum dots. Encapsulated in film and free of cadmium, these powerful dots can be fine-tuned to ensure healthy plant growth at every stage of

development. LED lighting manufacturers who adopt this technology will be able to offer farmers a consistent, cost-effective method of growing that's safe, reliable, energy- and cost-effective, and satisfies customer needs worldwide. ■

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- [1] The effects of light-emitting diode lighting on greenhouse plant growth and quality. Margit Olle and Akvile Virsile, from Agricultural and Food Science Vol 22, No 2 (2013)
- [2] Vertical Farming Market by Functional Device (Lighting, Hydroponic Component, Climate Control, and Sensors), Growth Mechanism (Aeroponics, Hydroponics, and Others) and by Geography - Global Forecast to 2020. Markets and Markets



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LMT Lichtmesstechnik GmbH's latest KUKA robot based goniometer

## Next LpR LIFETIME & RELIABILITY Issue 56 - July/Aug 2016

### TECHNOLOGIES

#### Concepts to Overcome Lifetime Issues of LED Drivers

In recent years, after a century of little to modest advancements, lighting technology has changed significantly. LED luminaires offer advancement in lower power consumption and expected life. However, if attention is not paid to the drivers and power supplies used to power LEDs, this new technology will also lower life and reliability expectations. The main components affecting lifetime are known but how to eliminate them or design a product that will achieve the desired lifetime is not easy. This article shows how to get the best possible solution. ■

#### Fiber Optics Technology for Applications

Often technologies that are too expensive for the mass market are adopted in medical applications. When reaching a certain level of maturity, costs usually become more reasonable and adaptations for the consumer market begins. Fiber optics technology could become one of these technologies for some selected applications. The technology and its prerequisites are discussed in this article. ■

### RESEARCH

#### "Best Papers" at LpS 2015: Quality of LED Lamps for Residential Lighting in European Market and Associated Health Issues

Due to shortfalls regarding consumer information for high quality energy efficient substitute products for incandescent lamps, significant irritation among buyers and a negative attitude towards LEDs has been enforced. This negative perception has been further amplified by the fact that low quality products are still flooding the market. More than 370 lamps and 95 different types were tested. The results and some aspects of photo biological safety (blue light risk) of LEDs are disclosed. ■

### SPECIAL

#### LED Lamps Recycling Technology for a Circular Economy

While having a long propagated lifetime, LED lighting products, especially lamps, have a foreseeable end of life. Because the products contain valuable resources, environmental concerns ask for them to be recycled. As with other highly integrated electronics products this is not a simple task. A method that could open the way to the successful recycling of precious components and materials is presented and discussed. ■

subject to change

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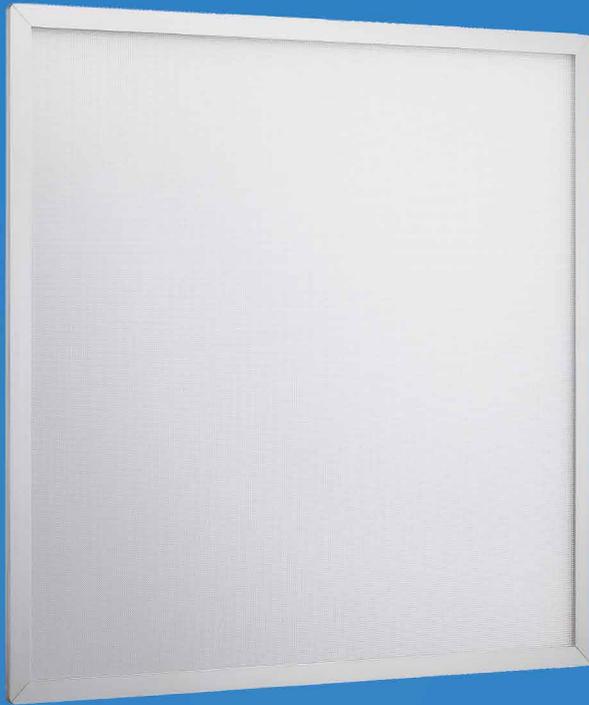


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