LED professional Review

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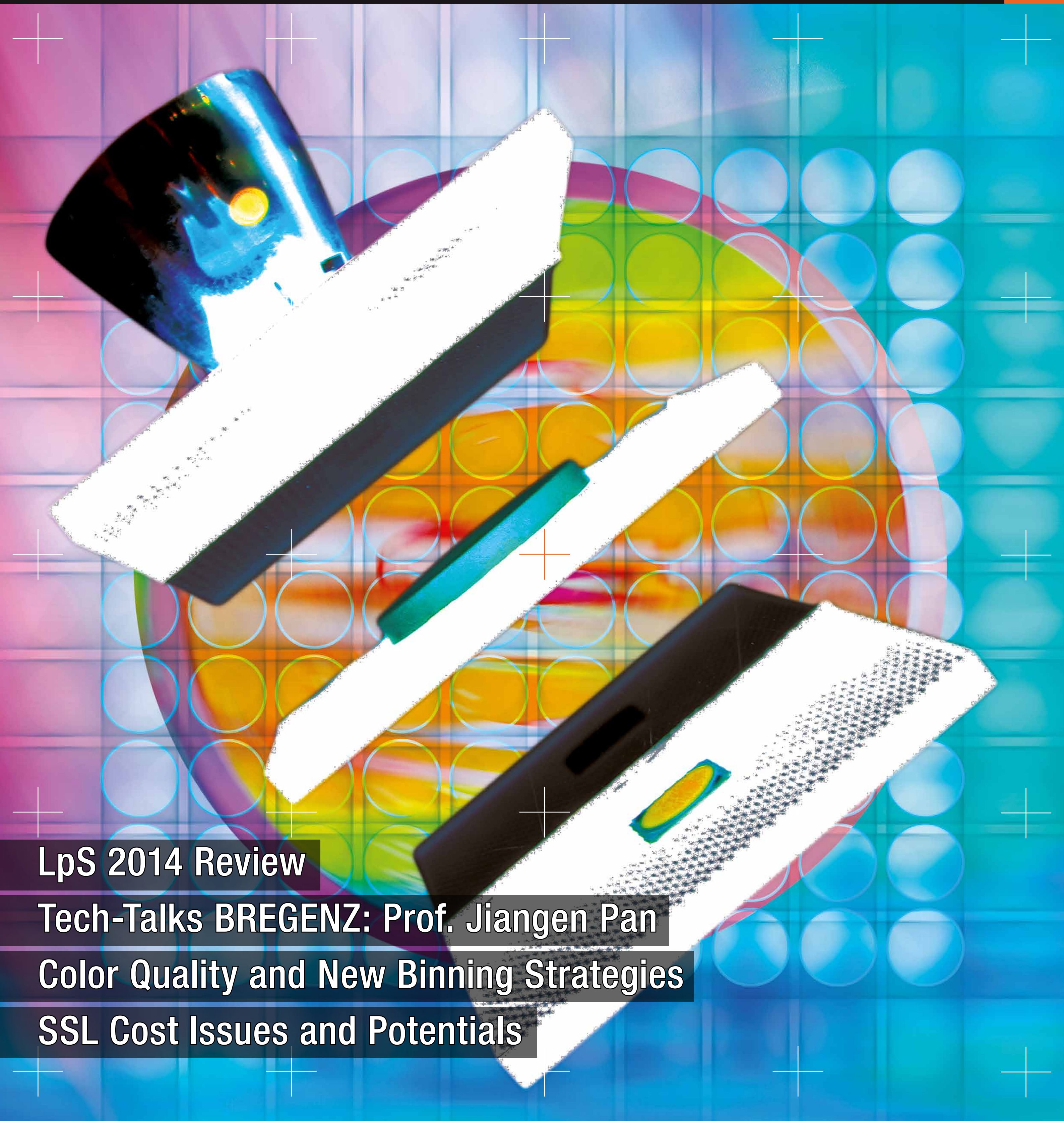


LpS 2014 Review
Tech-Talks BREGENZ: Prof. Jiangen Pan
Color Quality and New Binning Strategies
SSL Cost Issues and Potentials

LED professional Scientific Award

Industry and academia are making big efforts in research and continuously working towards the further development of solid-state lighting technologies on all system levels. Even if we just focus on the academic domain it's hardly possible to track or evaluate the outcomes of this research work. Therefore we believe that a careful selection of the best scientific papers in the field of LED lighting is extremely useful, helping to set the future trends for the industry.

This year, for the first time, the LED professional Scientific Award was presented at the LED professional Symposium +Expo 2014. An international jury made up of leading scientists made their recommendations so the winner could be chosen from the many universities and research institutes that were encouraged to submit a paper on the subjects of LED and OLED light sources, according to the "Call for Papers Guidelines". The evaluation criteria were the relevance for the lighting industry, the degree of novelty and the scientific work.

As a part of the LpS 2014 opening ceremony, Dr. Peter Bodrogi, Technical University of Darmstadt, Germany was awarded EUR 3,000 for his paper titled: "New Binning Strategy for White LEDs to Improve the Color Quality of Interior Lighting".

Mr. Stoil Kordev, from Optonica LED, the Scientific Award Sponsor, was present to hand over the check to Dr. Bodrogi during the ceremony.

Dr. Bodrogi and his team recognized the deficiencies of the ANSI chromaticity binning strategy resulting from the use and magnification of MacAdam ellipses. They developed a new strategy for white LEDs based on an updated color-space (CAM02-UCS) and on easy-to-understand binning categories e.g. "very-good". These semantic categories communicate the magnitude of chromaticity differences between LED light source manufacturers and producers of interior lighting products very effectively.

Please take the time to read Dr. Bodrogi's full study in this LpR issue. Furthermore, an additional five selected papers from the evaluation process will be published in the LpR issues throughout the coming year.

The LED professional Scientific Award will be presented again in 2015.
The Call for Papers opens in January 2015.

Yours Sincerely,

Siegfried Luger
CEO, Luger Research e.U.
Publisher, LED professional
Event Director, LpS 2014

Content

Advertising Index

Alexander Woerle

The trained electronics engineer and total quality manager has been at kdg for 23 years. During this time he has not only gone through the important manufacturing areas of the company, but also significantly helped to design almost all the innovation and manufacturing processes. Since 2003, Wörle has also been the person primarily responsible for R&D. In 2012, Wörle was entrusted with the division management of kdg mediatech, and in the previous year he was appointed as Managing Director. Wörle is also CTO of kdg's own start-up kdg-Opticomp, which was started in 2012 with the aim of establishing a competence center for high-precision optical injection molding.

OTHER DISRUPTIONS COMING OUR WAY

When the LED professional editorial department asked us to contribute something on the topic of costs and processes, we were very happy to say yes. But if you are expecting a holier-than-thou, very keen essay on savings and optimization potential in cost structure and manufacturing processes, unfortunately, we're going to disappoint you.

We won't bother boring you with exact details and quite possibly confirming your assumption that everything previously given away in project kilometers can be made up for in manufacturing. Our original business tells us that if you're not fast enough, you'll lose out. But the LED business is speeding up a level. When we entered this business, the thing we noticed straight away was that this branch seems to have endless amounts of time and sometimes projects stretch out as if time isn't a cost factor.

Right at the beginning, we were confronted with an almost duplicitous statement: We are in high-precision optical injection molding and not on the run. Never being on the run in 30-checkered years in optical media manufacture, you learn to face facts.

Even so, we found ourselves faced with lines of reasoning that made us want to run. For example, after an infinite number of loops were made in the project development and design that was hardly ever coordinated with the person that should bring the elaborately calculated algorithms into shape, we continually heard the following: The part should be high-precision, play all optical pieces, be a shining reflection of your light distribution and cost next to nothing. At one point the customer's request for the highly complex filigree physical artworks end up in a complex tool, where it is plain to see that even if you wish for identical octuplets for Christmas, you're not going to get them.

Normally, the prices are already calculated in such a way that the machine should produce perfect parts shortly after switching it on.

Unfortunately, it doesn't work like that. So you ask yourself the justified question: Who will pay for optimization times, in which the machines and personnel are blocked from working on really productive jobs? We have heard it is better not to ask that type of question, but we ask it anyway.

What is even more surprising is that even though the identical octuplets are an illusion they are produced somewhere in the East where the workers are cheap. They sort the tools according to the Cinderella principle of the good into the pot and the bad into the crop. This is known commonly as optimization and quality assurance. But we think optimization should start much sooner.

The time it takes until customers can finally get their parts and fine-tune them is currently much too long. Ultimately, in high-precision injection molding, there should only be parts that claim the attributes of high precision and which are perfect for the solution approach and design as well. However, this can only happen in the closest possible collaboration with the manufacturers, who therefore should be included in the project process as early as possible. It's too late to involve them in the final step when everyone is already annoyed about the infinite loops that were decided without the implementer.

After one and a half years in this sector we have to say that we didn't enter into manufacturing high-precision optical components to patiently watch the sector go through its trial-and-error learning processes. That is guaranteed never to increase the drive. And drive is precisely what the branch needs now. Because ultimately, we are already at the beginning of a disruptive process, triggered by the technological advances of 3D printing, generative manufacturing technology, and the Internet of Things. And those who ignore these signs won't get the chance to optimize their existing processes, because they simply won't exist anymore. ■

A.W.

Ledlink Optics,Inc.

NEW PRODUCTS

Single Lens

LL01NI-BNX38L02
DxH(mm) 44x14.6
FWHM 38° (24°developing)
Nichia 757x7

LL01WT-BSSxxL46
DxH(mm) 44x12.2
FWHM 24° 32° (15°developing)
Cree CXA1304/1507/1820
Citizen CLL 010
Nichia 024B/036B/060B
ProLight 7W COB

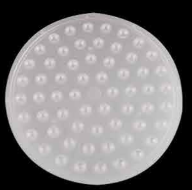
Reflector

LL01LU-BRS22R49
DxH(mm) 90x50
FWHM 22°
Luminus CXM-18
(Connector:LL01A00SVFB2-M2)

LL01CR-BSAxxR49
DxH(mm) 75x26.9
FWHM 12° 18°
CREE CXA1304/CXA1507
(Lens: LL01CR-BZG100L51)

Multi Lens

LL04TS-BTB20L06-M3
DxH(mm) 32x8.05 FWHM 20°
Cree XPE2/XPG2/XTE/XPL
Nichia 757A,D/NVS19B/NCS19B
Lumileds Rebel/Rebel ES
Samsung 351B
LGInnotek 3535 G2



LL60CR-BOQ30L02
DxH(mm) 215.6x11.8
FWHM 30°
Cree XBD/XPE

Street Lamp Lens

Type II

LL04CR-BXJ80150L02
DxH(mm) 50x50x7 FWHM 80°x150°
Cree XPE/XPG/XPG2/XTE/XPL
Osram Oslon square
Nichia NVS19B
Lumileds Rebel ES
LGInnotek 3535 G2

Type III

LL04CR-BXJ45155L02
DxH(mm) 50x50x7 FWHM 45°x155°
Cree XPE/XPG2/XTE/XPL
Osram Oslon square
Nichia NVS19B
Lumileds Rebel ES
LGInnotek 3535 G2

4 IN 1 LENS HOLDER (Can be compatible to DF, BDF & AAF series Lens)

Holder: LL04CRSW40H2
DxH(mm) 37x10.61

Part Number	CREE XBD	CREE XPE	CREE XPE2	TSMC TH3/TH5
LL04ZZ-AAA30L06-M2	V	V	V	
LL04ZZ-AAA40L06-M2	V		V	V
LL04ZZ-AAA50L06-M2	V	V	V	
LL04ZZ-AAA70L06-M2	V	V	V	
LL04ZZ-AAA90L06-M2	V	V	V	V
LL04ZZ-AAA3065L06-M2	V	V	V	
LL04ZZ-BBB40L02-M2		V	V	V
LL04ZZ-BBB70L02-M2	V	V	V	V
LL04ZZ-BBB100L02-M2	V	V	V	V

Our Services

- R & D
- Precision Mould
- Manufacture
- Component solution
- Customerization

Further technical information is available, please contact us for more details.

| www.ledlink-optics.com | service@ledlink-optics.com

LedLink
Linking LEDs to The Real World

Addition to Philips Lumileds LUXEON CoBs Delivers Exceptional Punch

In an expansion of its highly acclaimed LUXEON CoB line, Philips Lumileds introduced a compact array that delivers industry-leading center beam candle power (CBCP), the LUXEON CoB 1202s. The array's small size makes it the ideal choice for designers of PAR lamps and other compact directional lamps. The LUXEON CoB 1202s is also available with CrispWhite Technology, which highlights the richest whites, vibrant reds and colors that pop in retail settings.

Lumileds newest LUXEON CoB 1202 array with a small, 6.5 mm light-emitting surface (LES) enables the highest center beam candle power with the high efficacy and color quality of all LUXEON CoB solutions

Philips Lumileds' unrelenting pursuit of "punch" led to this latest CoB design. The 1202s lifts the bar even higher by producing light output in a smaller, 6.5 mm LES that was only possible previously in 9 mm LES arrays. In addition, the 1202s does so with a superior CBCP, delivering 65,000 candelas at a 10° beam angle.

Philips Lumileds first captivated the retail lighting community with Crisp White Technology when it was introduced across its chip-on-board line in July of this year. As an added benefit, the LUXEON CoB range including the 1202s is available in a very warm, 2200 K version for applications requiring a candlelight-like glow.

A full list of compatible drivers, optics and holders helps speed the time-to-market of all downlights and spotlights as well. ■

Bridgelux Launches New "Human Centric" CoB LED Arrays

Bridgelux, a leading developer and manufacturer of LED lighting technologies, debuted its new Vero® Décor Series™ Class A Chip-on-Board (CoB) LED array products at the Hong Kong International Lighting Fair 2014. The launch of the Décor Series Class A arrays marks Bridgelux's new "human-centric" approach to product development and color targeting by using Gamut Area Index (GAI) to measure how light and color appeals to and is perceived by the human brain.

Bridgelux adds the Décor Series Class A products to the Vero® series. These are the first commercially available LED arrays on the market to meet the full Class A Color specification

Available through global channels in mid-November, the new Décor Series Class A arrays are the first products to use the full Class A Color specification from the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute and the Alliance for Solid-State Illumination Systems and Technologies (ASSIST).

In research and development since 2002, Class A Color was created at the LRC with funding by ASSIST. Class A Color redefines high color quality of light. The long-term study examined how people perceive white light sources and what they prefer in terms of color rendering and the white hue or tint of a light source. Bridgelux specifiers and engineers developed prototype lamps based on the Class A Color spectral requirements for the LRC to use in field evaluations.

Distinguished by its human appeal, brightness and natural rendering, Class A colors are inherently more vivid and whites are their whitest due to a broader spectrum of colors and saturation. By achieving a balance of color properties that match how people perceive color, the Bridgelux Décor Series Class A LED arrays not only deliver superior color quality but also provide a better return on investment when compared to traditional halogen and ceramic metal halide bulbs.

Décor Series Class A LEDs consume 30 percent less energy, generate 70 percent less heat, and last 20 times longer than halogen or metal halide light sources.

Lighting has become a critical design feature for high-end retail and commercial spaces, with solid-state LED technologies playing a vital role in helping businesses differentiate and stand out to their customers. Whether creating ambience in a luxury hotel lobby, showcasing merchandise in a retail store or illuminating museum works of art, Décor Series Class A LED arrays deliver a stunning visual experience by appealing to people's natural perception of light, helping to drive improved aesthetics, increased visits, customer purchases and revenue per square foot.

Traditionally, the lighting industry uses Color Rendering Index (CRI) as a primary measure of light quality; however, CRI only measures color distortion. Gamut Area Index (GAI) measures color saturation and strength to

more accurately reflect the holistic effect of light and how a person will perceive color. Bridgelux Décor Series Class A is engineered at the optimal GAI and CRI combination based on human perception of light.

Bridgelux Vero Décor Series Class A arrays will be available in 4000 K and 3000 K CCT. They're designed for applications including high-end retail, hospitality, museums and commercial spaces. ■

Luminus' XNOVA Cube™ - Tiny 1W SMD LED with Extremely Wide Emission Angle

Luminus Devices, Inc., a global manufacturer of high-performance LEDs and solid-state light sources, announced the launch of the XNOVA Cube, an innovative 1 watt SMD LED with a 170 degree viewing angle, which provides designers with the ability to improve system efficacy, reduce cost, and simplify omnidirectional products. Unlike traditional mid-power LEDs, which were originally designed for LCD backlighting, the XNOVA cube is engineered specifically for illumination applications with high quality of light requirements, has the industry's widest viewing angle, emits more light than any midpower LED, and delivers all this from a compact 1.9 by 1.9mm package.

Luminus' new XNOVA Cube enables customers to use fewer LEDs, improve uniformity and reduce system cost while retaining best in class quality of light

"The XNOVA Cube has opened-up new design options for our customers in the highly competitive panel lighting, linear and omnidirectional lamp markets," said Jim Miller, Executive Vice President of Sales and Marketing for Luminus. "They are able to reduce LED count by as much as 30% and at the same time cut power consumption by 10%, which enables further cost reductions in drivers, thermal systems, and optics." ■

Cree Redefines HP LEDs for Lighting with New SC5 Technology Platform

Cree, Inc. achieves another fundamental breakthrough in lighting-class LED performance with the groundbreaking SC5 Technology™ Platform. The new platform powers the next generation of lighting with the introduction of Extreme High Power (XHP) LEDs. This new class of LEDs can reduce system costs by up to 40 percent in most lighting applications.

With its new SC5 product platform, Cree introduces L90 lifetime at higher operating temperatures as well as higher lumen density in combination with high efficacy

The SC5 Technology Platform is built on Cree's industry-best silicon carbide technology and features significant advancements in epitaxial structure, chip architecture and an advanced light conversion system optimized for best thermal and optical performance. With these advancements, the SC5 Technology Platform achieves unparalleled lumen density and longer lifetime at higher operating temperatures than previous LED technology, which can significantly reduce thermal, mechanical and optical costs at the system level.

The first available family of XHP LEDs is the XLamp® XHP50 LED, delivering up to 2250 lumens at 19 watts from a 5.0x5.0 mm package. At its maximum current, the XHP50 provides twice the light output of the industry's brightest single-die LED, the XLamp XM-L2 LED, at a similar lumens per watt and without increasing the package footprint. By leveraging Cree's latest reliability innovations, the XHP50 is designed to maintain L90 lifetimes above 50,000 hours even at high temperature and current. ■

ProLight High-Current LED-Grande 3535

ProLight's Grande 3535 is a high-current LED in a single chip package. The light output of Grande 3535 can reach 360 lm at the current 1200 mA. Grande 3535 adopts ProLight's exclusive technology which can solve silicon chap and heat resistance problems to provide the best lm/$.

Prolight Opto's Grande 3535 can provide up to 360 lm at 1.2 A

Specification:
- Size: 3.45 x 3.44 mm
- Watt: 5 W (1200 mA @ 3.6V)
- Lumen: 360 lm

Features:
- High Thermal Eutectic Technology

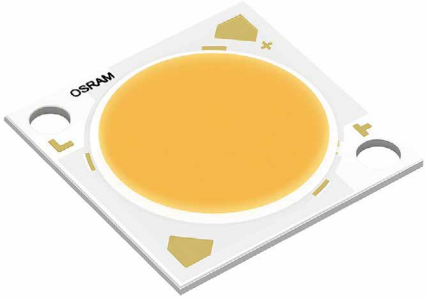
Grande 3535 adopts ProLight's High Thermal Eutectic Technology, which can reduce heat resistance similar to flip chip. In the lifetime test, the aging trend of Grande 3535 is almost the same as flip chip.

Special Silicone Formula
Grande 3535 adopts an optical grade silicone formula which can avoid large lumen depreciation caused by silicon chap when energy is too intensive.

Exclusive Phosphor Coating Technology
Grande 3535 uses patented phosphor coating technology. This technology will resolve light uniformity issue faces when using horizontal die which emits in all direction. The package is suitable for applications that use 2nd optics such as directional lighting and wall washer. ■

Osram Announces New Soleriq S 19 Versions with Two Different CRIs

Osram Opto Semiconductors launches new product versions of the Soleriq S 19 with two different color-rendering indexes (CRI). As with all versions of the S 19 the new LEDs can be used in all applications where high lumen packages from a compact light source are needed.



Osram's updated Soleriq S 19 LEDs offer CRI 80 or 90 and between 2,000 lm an 5,000 lm

Technical Information:
- Package Size: 24 mm x 24 mm x 1.4 mm
- Brightness & Efficacy (at 4000 K / 85°C):
  CRI 80: 2800 lm, 117 lm/W
  5361 lm, 116 lm/W
  CRI 90: 2420 lm, 101 lm/W
  3400 lm, 104 lm/W
  4610 lm, 100 lm/W
- Light-Emitting Surface (diameter): 19 mm
- Color Temperature: 2700 to 4000 K

The new Osram Soleriq S 19 LEDs are available with color rendering indexes (CRI) 80 and 90. There are two CRI 80 versions with brightness values of 2000 and 5000 lumens (lm) and three CRI 90 LEDs with 2000, 3000 and 5000 lm. An S 19 LED with CRI 80 and 3000 lm has already been launched. As with all Soleriq S 19 LEDs the new products are based on the standards defined by Zhaga and have a light-emitting surface with a diameter of 19 mm.

With the new product versions Osram Opto Semiconductors now offers one LED family (Soleriq) with similar package size and various lumen and CRI options, so customers neither have to change optic and reflector design nor connectors when upgrading their product range. Furthermore, the LEDs can be driven in low-current mode to achieve even higher efficacies or in high-current mode to achieve high light output. In this way, different requirements of luminaires can be met with the same set of optics and holders.

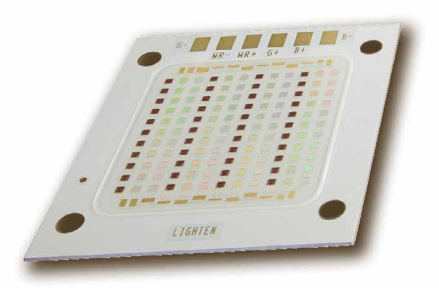
When installed in lamps and luminaires, the new Soleriq S 19 LEDs can be used for professional downlight applications in offices and shops but also for hospitality lighting. They offer a high flexibility in this context:

If customers want to implement lighting solutions in rooms with lower ceilings, e. g. offices, they can choose the S 19 version with 2000 lm. If rooms with high ceilings are to be illuminated (e. g. shopping malls), an LED with a high lumen package is the perfect choice.

All Soleriq LEDs are based on Chip-on-Board technology. This technology guarantees a uniform color and light appearance thanks to the close arrangement of the chips beneath a conversion layer. The LEDs are very simple to work with as they are screwed to the heat sink with a connector. Then the connecting wires just need to be inserted into the connectors provided and fixed in place. There is no longer any need for SMT (Surface Mount Technology) soldering. Accessories such as connectors, optics and drivers tailored to the Soleriq family can be obtained by the Osram partner network LED Light for you (LLFY). Customers can either go to the LLFY website or use the free "LLFY Selector" app so they can find the perfect products on the move. ■

Lighten Releases a New Generation of High Power Multi-Color CoB-LEDs

Thanks to LED solutions for general lighting maturing, Taiwan Lighten Corp. succeeds in leveraging their excellent knowledge & experience in high-end general lighting to an even more challenging field - professional stage lighting applications. Lighten can achieve their next targets with higher color performance / uniformity / multi-color mixing / high power output / high CRI values, as they know from the most important industry users' VOC.



Lighten's latest CoB LEDs are multi-color CoB LEDs primarily targeting professional stage lighting applications

Features of Lighten's stage lighting COBs:

- All COB structure (3 W~500 W), small emitting area and good for optical lens design. Solid /sharp shadow
- Excellent system thermal dispassion design, lower system Rth values, by high-grade copper interposer / substrates
- <3 steps of SCDM, and lower thermal color shifting
- Less than 3% of thermal efficiency decay. (More than 3000 hours continuous light-on)
- Anti-vulcanization treatment, no surface discoloration issue
- CRI (Ra) > 95 & R9> 80
- Multi-color COB array design (RGB / RGBA /RGBW), individual driver input. (DMX system compliable)
- Suitable for common industry parts and ODM is acceptable
- Made in Taiwan, high grade quality control, quick lead time

Rod Lin (CTO of Lighten Corp.) says, "We are proud to release our CoB products for LED stage lighting applications from 5 W~500 W, with high Ra value (CRI~98), multi-color array design (RGB / RGBW). Of course these new products also offer our typical Lighten CoB features like low system Rth (< 0.52) & anti-vulcanization and higher COB efficiency." He than added, "By integrating all features we can ensure that the next generation LED stage lighting can provide higher power output, color stability, well multi-color mixing, uniformity, sharp light bin angle, and the most important is the true color like fixture results." ■

New Generation of High-Power LEDs for Better Performance and System Cost

Cree, Inc. introduces the XLamp® MH-B LED, a new generation of high-power LEDs that delivers better performance and a more-effective way to achieve low-cost systems than mid-power (MP) LEDs. Using Cree's high-reliability ceramic package technology, the XLamp MH-B LED is able to operate at higher temperatures than MP LEDs with no reduction in rated lifetime, enabling an impressive 60 percent reduction in heat-sink size and cost. Using up to 26 times fewer LEDs than MP LEDs to achieve the same level of performance, the XLamp MH-B is optimized to simplify LED system designs for applications where multiple MP LEDs are currently used.

Cree's new XLamp® MH-B LED intends to reduce costs and simplify LED system designs

XLamp MH-B LED "Cree has once again invented a lighting-optimized solution that can lower my costs and decrease manufacturing times," said Frank Chen, technical director, Zhejiang Shenghui Lighting Co., Ltd. and Sengled Optoelectronics Co., Ltd. "While chip-on-board LEDs are an attractive alternative to

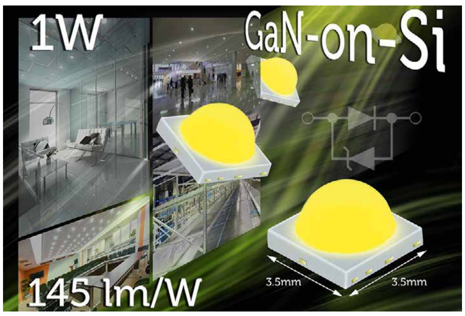
MP LEDs in terms of reliability and cost, they aren't compatible with my automated manufacturing processes. The new XLamp® MH-B LED finally gives me a more-reliable alternative to mid-power LEDs – I no longer have to compromise my brand and reputation to achieve a lower system cost."

Featuring Cree's EasyWhite® technology and a small 5-mm light-emitting surface, the XLamp MH-B provides many system benefits over arrays of MP LEDs, including tighter beam angles, simpler optics, a more-traditional appearance and easier color consistency. As a single LED, the XLamp MH-B LED delivers up to 830 lumens at 175 mA and can also be used in arrays to address higher-lumen applications that require low cost and high reliability, such as high bay, outdoor area and downlights.

The XLamp MH-B LED is available in 2700 K to 6500 K with high-CRI options. Product samples are available now, and production quantities are available with standard lead times. ■

Toshiba Launches High-Performance Ultra-Compact White Lens Type 3535 LEDs

Toshiba Electronics Europe (TEE) has extended its LETERAS™ family of white LEDs with a new series of ultra-compact devices that combine cost-effective gallium nitride-on-silicon (GaN-on-Si) chips with an industrial standard 3535 lens type package.



Toshiba's new GaN-on-Si white LETERAS™ LEDs simplify general-purpose and industrial lighting designs

Devices in the TL1L3 series of 1.0 W LEDs are supplied in a package with a footprint of 3.5mm x 3.5mm and a height, including lens, of just 2.42 mm. Despite their small size the LEDs deliver typical luminous flux ratings of between 112 and 145 lumens, depending on the correlated color temperature (CCT).

Toshiba's latest LEDs with integrated lens are suitable for implementation in tube lights, light bulbs, down lights and ceiling lights, as well as street light and floodlight designs.

The new TL1L3 LED series comprises seven devices offering color temperatures from 2700 K to 6500 K. Minimum color rendering index (Ra) ratings of up to 80 contribute to natural looking lighting across all target applications. A low typical forward voltage (VF) of just 2.85 V (at a forward current of 350 mA) helps to keep power consumption to a minimum.

High-performance white LEDs have typically been fabricated on expensive sapphire substrates using relatively small 100 mm or 150 mm wafers. Toshiba LETERAS LEDs, however, use a highly cost-effective GaN-on-Si process technology that allows GaN LEDs to be produced on 200 mm silicon wafers.

TL1L3 LEDs are rated for operating temperatures between -40°C and 100°C and have a maximum power dissipation of 3.4 W. Additionally they offer a very low typical thermal resistance Rth(j-s) from LED junction to solder point of only 5°C/W. ■

Everlight Introduces a Natural Light CoB LED Series for Higher Quality of Lighting

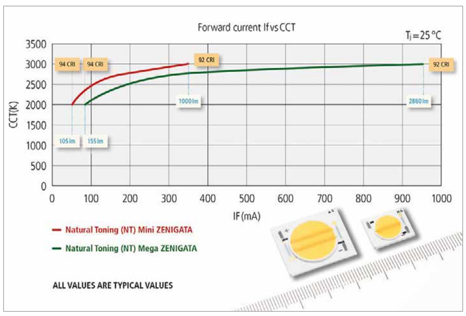
Everlight, a leading player in the global LED and optoelectronics industry, supplements its LED Lighting product portfolio, currently featuring a market-standard CRI of >80Ra, with higher color quality versions. The new Natural Light LED variants will provide a CRI >95Ra, averaging 98Ra. Everlight is pursuing this goal a step at a time. The first LED series to implement the Natural Light Technology is Everlight's 3-50 W Ceramic COBs (JU Series) and Metal PCB CoBs (XUAN Series). All other LEDs will offer Natural Light versions in Q4 of 2014.

Everlight's new 3-50 W Ceramic COBs (JU Series) and Metal PCB CoBs (XUAN Series) addresses the market requirements for higher quality of Lighting LEDs

Color rendering, a quality characteristic of light, is the effect of an illuminant on the color appearance of an object by conscious or subconscious comparison with their color appearance under a reference illuminant. One major objective of LED lighting manufacturers is to achieve a light quality that can replace or emulate the ultimate reference of the sun. In other words: a CRI of 100Ra. To reach this goal would bring sunlight indoors, sustain sunlight during the night, replace traditional incandescent and halogen lamps which usually feature high color quality, and change the way we perceive and appreciate our surroundings. ■

Sharp's New Natural Toning ZENIGATA LED Line Dims to Warm CCT

Sharp Devices Europe has announced a new line of LEDs with a single emitting surface that produces warmer light when dimmed. The new Natural Toning LEDs vary their color temperatures across a range from 3000 K to 2000 K and come in two sizes, Mega and Mini.



Sharp's new Natural Toning LEDs vary their color temperatures across a range from 3000 K to 2000 K which mimics the dimming-behavior of halogen lamps

LED efficiency, incandescent color response: Standard LEDs normally maintain a constant color temperature regardless of intensity. In this respect, they differ from halogen and incandescent bulbs, which make warmer light when dimmed. To reproduce this black body curve familiar from incandescent lighting, Sharp has designed a new line of dim-to-warm LEDs that require no additional controls beyond a dimmer.

Ideal for home and hospitality applications: In restaurants and at home, we have come to expect a warm glow when the lights are turned down low. Tunable LEDs are one way to achieve that result, but at the cost of additional control equipment and the associated expense. With its new Natural Toning LEDs, Sharp has integrated the control circuitry right on the LED device itself. The new Sharp LEDs produce warmer light as current declines, mimicking incandescent lighting.

Outstanding color quality: Especially for high-end commercial and retail applications, color quality is a major factor impacting both lighting design and interior decorating choices. The new Natural Toning LEDs from Sharp provide very high color quality, with typical CRIs ranging between 92 and 94 across their intensity range. The warmer and cooler blocks of these phosphor coated LEDs are also combined under a single light emitting surface, ensuring uniform color distribution without the complexity of RGB-array solutions.

Flexibility and power: At an operating current of 350 mA, the Natural Toning Mini ZENIGATA delivers up to 1000 lm with a color temperature of 3000 K. When dimmed down to 50 mA, the Mini puts out 105 lm at 2000 K. Its big brother, the Natural Toning Mega ZENIGATA, typically produces values ranging from a high of 2860 lm at 950 mA and 3000 K down to 155 lm at 2000 K. ■

Edison Opto Introduces EdiPower Special Light Series

Edison Opto has developed EdiPower II HM30 special light series to match fresh foods, clothes and skin colors. For clothing lighting, Edison introduces Snowhite LED which approximates the effect of traditional CDM and is able to present the clean and pure texture of fabric or clothes. In addition, the 3000 K color temperature and high CRI (>80) make it possible for Snowhite LED to create a warm display space and the clothes' true colors appear. Therefore, it is suitable for showcasing merchandise in clothing stores.

With EdiPower Special Light Series, Edison Opto supports different requirements for special lighting tasks from bakeries to clothing stores and beauty shops

Features:
- Provides wide range of special lighting solutions which can enhance the visual appeal of merchandise effectively
- High CRI: brings out the actual luster of objects
- Especially suitable for colorful accent lighting

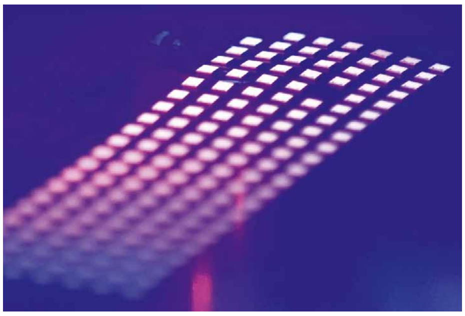
Applications:
- Snowhite - Clothing store
- Aroma - Bakery
- Ruby - Supermarket and flower shop
- Mela - Beauty makeup shop

For bakery lighting applications, Edison's Aroma LED (2400 K) presents champagne gold color that can help to emphasize the sheen of bread, cheese and wine, making food look more tasty and attractive. Moreover, Edison Opto also develops a special phosphor proportion to emit deep pink light (Ruby LED), which can enhance the red in fresh meat and flowers. EdiPower HM Ruby LED is the best choice of supermarket and flower shop.

LED lighting can not only enhance the appearance color of food and clothes but also beautify the human skin. Edison Opto launches Mela LED which can bring out the rosy luster of natural skin. Featuring high CRI (up to 90), EdiPower HM Mela LED is the perfect match for beauty makeup lighting. ■

New Chip Scale ReadyMount™ EC LED Series from SemiLEDs

SemiLEDs Corporation, a global provider of vertical LED technology solutions, announced sampling and mass production availability of its newest line of white chip scale packages, the ReadyMount™ Enhanced CSP, or EC series. By combining SemiLEDs' Enhanced Flip chip (EF) approach with the company's innovative ReadyWhite™ phosphor technology, the EC delivers unprecedented flexibility, reliability and manufacturability in a single 1.4 x 1.4 mm low profile device. Rated for input power of up to 3 W, the EC is a fully packaged white emitter SMD component, ready for surface mounting on any board level module or COB application, lowering capital costs and enabling extremely high lumen density configurations.



LED dies from SemiLEDs

The new ReadyMount white chip scale package is leveraging a powerful synergy within SemiLEDs' broad technology portfolio to create an entirely new value point in the LED industry. The unique Chip Scale Package (CSP) reduces final component cost up to 50%, with a packaging cost reduction of up to 80% over conventional packaging. EC Series products, such as the EC-W1414, enable system-integrators and luminaire manufacturers a direct path to a highly cost effective solution on a per-lumen basis now, with additional viewing angles and die sizes under development.

The ReadyMount products will provide particular benefit to light-engine and luminaire manufacturers who have previously had to rely exclusively upon packaged die solutions. Incorporating SemiLEDs' EF Series FlipChip, the electrical contacts are moved to the bottom of the chip leaving an emitting surface that is uninterrupted by wire bonds or top-side electrodes. The result is a compact chip scale package, only 0.4 mm high, which can produce outputs of up to 300 lm at 1 A. The SemiLEDs EC series is available in standard ReadyWhite™ CCTs ranging from 2,700 K to 10,000 K with color rendering indices up to 90 minimum.

The elimination of the wire bonds also improves the optical integration characteristics by taking advantage of the unobstructed and nearly edge-to-edge emitting chip surface that enables the die to be mounted very close together. This simplifies the optics by eliminating the need for complex mixing lenses which are used to control ghosting and shadows in narrow beam applications. The glass top surface is also very mechanically robust, and is not prone to the handling damage or stresses faced by wire-bond or flip chips with a silicone covering. The typical 145 degree field of view also demonstrates good color-over-angle characteristics as a result of the ReadyWhite technology.

By enabling densely packed mounting with simplified optics, the SemiLEDs EC series is ideal for general lighting applications including indoor and outdoor lighting, architectural lighting, and torches/flashlights. ■

Sharp Devices Europe Extends LED Portfolio at LpS 2014 with Intermo Module

Sharp Devices Europe has launched an important new portfolio of LED modules dubbed Intermo. This latest addition to Sharp's range of LED products includes two easy-to integrate module packages.

Sharp Devices Europe's new Intermo modules were demonstrated to the public for the first time at LpS 2014 in Bregenz/Austria

Exhibition highlight
Sharp Devices Europe introduced its new LED module family Intermo at the International LED Professional Symposium + Expo which was held from 30.9.-2-10.2014 in Bregenz, Austria. Sharp's Intermo products were showcased in a full Eco-System at the booth of our solution partner, SILICA. The new Intermo LED spot modules attracted a great deal of attention as one of the exhibition's highlights.

Two module sizes:
The latest additions to Sharp's LED line-up come in two module sizes, standard and slim. 50 mm in diameter and 6 mm high, the Standard Intermo is a Zhaga Book 3 form-factor module, which ensures compatibility with a large eco-system of third-party products. The somewhat smaller Slim module, which is 44 mm in diameter and 3.6 mm high, has a nicely compact form factor, which is ideal for luminaire designs where space is at a premium.

Market-leading performance:
The two Intermo modules are based on integrated Sharp Mega ZENIGATA LEDs and will include the latest high-efficiency technology. As a result, they will offer a market-leading performance in a range of luminous flux, color temperature and color rendering options.

Integrated thermal interface material:
The fact that both Intermo modules come with integrated thermal interface material (TIM) ensures that the luminaire manufacturer will find integration extremely easy. Only two screws are needed to secure the module to the heat sink and the integrated TIM simplifies thermal design. Other key features include solder-free electrical connectors and attachment systems for Carclo, Ledil, Ledlink and Khatod reflectors. ■

Edison Opto's 0.8 W Filament to Mimic Incandescent Lamps

The Taiwanese LED packaging manufacturer, Edison Opto, branched out into the filament market and released a 0.8 W LED filament. Used in a 4 W bulb, the LED bulb can replace a 40 W incandescent bulb, bringing the advantages of energy saving and high efficiency of an LED into full play.

Edison Opto's new LED filaments bring a visual experience which is similar to traditional incandescent lamps

Edison's 0.8 W filament uses packaging technology and serial LED chips to achieve 360° (omnidirectional) light distribution. With excellent light quality, the filament brings a whole new visual experience which is unlike traditional LEDs. As a result of using copper substrate as the lead frame, the filament has better heat dissipation and higher reliability performance. Furthermore, the luminous efficacy of Edison filament can reach 125lm/W (under 2700 K, CRI > 80) which is well-matched with sapphire substrate. With the advantages of high lm/$ and superior luminous efficiency, Edison's 0.8 W filament helps customers to achieve the same lighting effect and longer lifespan (up to 25,000 hours) with lower prices.

In most of the lighting market, general consumers are still accustomed to using traditional light sources. The LED filament bulbs can substitute incandescent bulbs directly and create a nostalgic lighting space. Edison's 0.8W filament is under mass production and can be ordered now. ■

Philips' Flex Innovatives Fortimo LED Downlight Module (DLM)

Royal Philips, the global leader in lighting, announced the availability of its new Fortimo LED Downlight Module (DLM) Flex range that gives luminaire manufacturers flexibility in the choice of LED module housing when designing downlight luminaires for offices, corridors and meeting areas in commercial buildings. The new module is also more energy efficient than its predecessor.

The Fortimo LED Downlight Module (DLM) Flex is 15% more energy efficient than its predecessor and is available in three different form factors

The new module also offers best in class lumen maintenance performance which means that the lumen output of the Fortimo LED DLM Flex depreciates less than any other module available in the market today.

Luminaire manufacturers now have the choice of three different form factors when using the Philips Fortimo LED DLM Flex.

Form Factors:

- LED board
- LED board in combination with shallow housing to create less bulky downlights
- LED board in combination with high housing, that matches the dimensions of the current Fortimo LED DLM Gen5 module, enabling an easy upgrade

The new module is 15% more energy efficient than its predecessor, the Fortimo LED DLM Gen5 module. It also offers the choice to either select a specific voltage or current combination to achieve the desired lumen output or a higher level of energy efficiency.

Luminaire manufacturers can also choose from a wider choice of Philips LED drivers that operate with the new Fortimo LED DLM Flex. This freedom of choice allows them to select the most suitable LED driver for the luminaire design, based on performance or cost considerations. ■

LeDiamond Double Side Emitting Multi-Color LED Module

LeDiamond Opto Corp. has announced the development of a double side emitting muti-color LED module. The new multi-color module may include red, amber, green, blue and CCT 2200 K, but also other colors.

Application examples of LeDiamond's new double side emitting muti-color LED modules

Features:

- External Dimensions 14.6 x 4.5 x 1.1 mm
- Internal Structure: Transparent Ceramic Base Chip on Board
- Luminous Flux:
  Red: 70 lm @ 40 mA
  Amber: 80 lm @ 40 mA
  Green: 120 lm @ 40 mA
  Blue: 20 lm @ 40 mA
- Thermal Resistance:
  Red, Amber and Green: 8°C/W
  Blue: 6°C/W
- RoHS Compliant

Multi-Color module creates Mood lighting/Special lighting environment which brings the concept of flexible lighting into the world of retail, making spaces more effective and meaningful. The mood can be changed constantly to keep pace with the new collections and trends.

The lighting color or CCT can also be adjusted by the needs of the designer.

The characteristics of the double side emitting LED reduced the total internal reflection in the package, also increased the light output efficiency. The external quantum efficiency increases more than 10% of the lighting extraction compared to a traditional LED package.

Philips Lumileds' Matrix Platform Redefines an Entire Module Category

Philips Lumileds announced that it has expanded beyond its well-respected LED product offerings to include Matrix Platform solutions. The Matrix Platform consists of turnkey LED solutions using components, optics and LUXEON LEDs assembled on a wide selection of board types. This platform launched with two product lines - the LUXEON XR and LUXEON XF - on rigid and flexible substrates respectively.

With the launch of the Matrix platform, Philips Lumileds delivers infinitely configurable LED boards, linear flex and modules using the industry's most comprehensive line of application-optimized LEDs

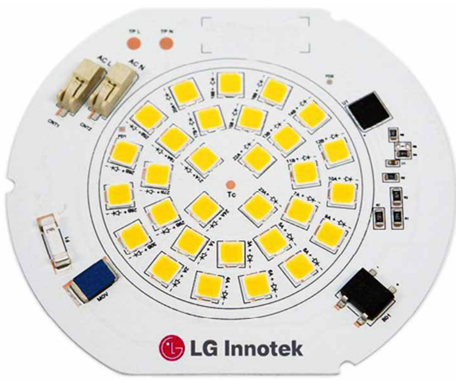
"More than ever, luminaire manufacturers need robust solutions that meet their specific design requirements. That need, together with today's time-to-market pressures, inspired our Matrix Platform," said Viral Hazari, Product Line Director for the Matrix Platform. Based on customer requirements, Philips Lumileds can provide LUXEON XR and LUXEON XF solutions designed with any LUXEON LEDs. Additionally, there are both "off-the-shelf" and "built-to-spec" options.

With Matrix Platform solutions, luminaire makers/designers benefit from faster time-to-market, simplified supply chain and access to proven illumination grade LUXEON LED performance.

Philips Lumileds first rigid substrate module product, the LUXEON XR-3535L for troffer applications, provides uniform, distributed light. Specified at 3000 K, 3500 K or 4000 K color temperature and a CRI of 80, the LUXEON XR-3535L achieves a lumen output of 1320 to 1515 lumens and an efficacy as high as 160 lm/W. For applications requiring a greater degree of design freedom and flexible substrate including accent lighting and cabinet lighting, the LUXEON XF-3535L produces from 1100 to 5070 lumens and an efficacy as high as 160 lm/W.

LG Innotek Extends Product Range with AC Direct LED Lighting Components

LG Innotek, a leading global materials and components manufacturer, announced that the company started to produce Alternating Current (AC) direct LED lighting packages and modules that will accelerate market adoption of the world's next generation lighting system.



LG Innotek's new AC direct modules are efficient in both design and cost and will accelerate market adoption of LED lighting

LG Innotek developed the AC direct LED by embedding a micro-drive integrated chip in the LED which controls the current. This allows the LED solution to occupy a smaller space since it does not require a SMPS unit and can reduce costs by up to 30 percent compared to conventional DC LED solutions.

LG Innotek is introducing a range of eight products; five types of AC direct LED packages, which is the basic component of LED lighting, and three types of lighting modules, which is an integrated LED package and printed circuit board. The company is planning to add two more AC LED packages and three more AC LED modules this year.

AC direct LED packages include the 5250HV(High Voltage), 3030HV and the 5630HV. The 5630HV produces 136lm/W, achieving the world's best light efficiency for an AC LED. The 5250 HV package optimizes costs in lighting systems, and the 3030 HV package is optimized for micro bulbs like G4 and G9. The 5630 HV and 5250 HV type packages have received LM80 certification, the U.S. reliability test standard for LED lighting.

The AC direct modules are targeted for down lighting applications. This product is especially favored by customers who value lighting quality because it provides light efficiency of 125lm/W, the best performance in 23W category (CRI is above 80), and an excellent light uniformity resulting from an optimized light pattern design.

LG Innotek's modules are not only made for outstanding performance, but also for maximizing customer convenience in the manufacturing of their finished lighting products. AC direct modules for down lighting have a light source placed in the center of the module to avoid dark spots and ensure uniform light distribution. The modules also simplify connectivity to the power source with built-in connectors.

The AC direct modules for bulbs have a surge protection circuit embedded in the product. It is ideal for lighting applications requiring size optimization, since it has a flexible design and reduces costs since it does not require auxiliary circuits.

LUXeXceL's Next Level 3D Printing Process for Optics Started at LpS 2014

LUXeXceL Group, the world's only additive manufacturer of optical components, announced both the launch of a new additive manufacturing platform that delivers high speed and precision as well as the introduction of a new clear material "LUX-Opticlear", allowing high quality optics manufacturing up to 20 mm in height.

At LpS 2014, LUXeXceL demonstrated the capability of manufacturing printed optics of up to 20 mm height for the first time at a fair

With these new capabilities, the LUXeXceL process is ready to compete with injection molding for the production of small and mid-sized series of optical components. The company now offers a fast and effective service for prototyping, iterating and the manufacturing of optics, cutting out the need for costly and inflexible tooling.

Digital manufacturing of optics:
The whole process is digital, allowing full flexibility and ordering on demand. This means that large inventory costs are no longer necessary. Small series or individual optics can be made in the space of a few days. Unique optical designs and components can be quickly tested and new designs can be validated. Adding up all these advantages in one single manufacturing service, LUXeXceL is now offering the full package to take on injection molding for small and mid-sized series.

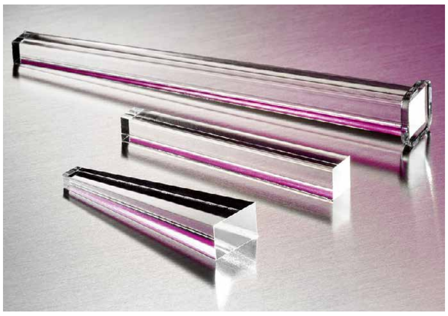
LUX-Opticlear printing material:
The new material, LUX-Opticlear, was developed by LUXeXceL to offer the best optical properties with a print height up to 20mm. This new material is the first of many more developments in the world of optical components.

The optical quality of the new LUX-Opticlear material combined with the digital advantages of this new additive process, makes LUXeXceL's service an affordable and attractive solution for both prototyping and smaller or mid-sized volume manufacturing of optical components.

These new capabilities combined with the "One-Step-CAD-to-Optic" manufacturing process is interesting for various industries, as new optical products and functions will arrive on stage and optics can be tailored to every application, project or even single product. ■

Auer Lighting Launches Borosilicate Based Glass Light Guides at LpS 2014

Beyond our already well known capabilities, Auer Lighting is proud to introduce the injection molding technology for advanced glass optics. This ground breaking technology enables Auer Lighting to produce light guides made from glass with added design features. Glass light guides are used in applications with high-power LEDs, e.g. automotive and stage lighting. They help to achieve the desired light distribution and color mixing.



Auer Lighting's borosilicate glass light guides - here some off-the-shelf examples - can easily withstand the high temperatures caused by high power LEDs that can irreversibly damage PMMA products

Other surface features offered include:
- IPolished input/output aperture
- ICoatings: AR, UV, color correction
- IMounting flange

Especially with high-power LEDs, temperatures can easily exceed the maximum operating temperatures of plastic materials like acrylic, PC, and even silicone.

Damaged PMMA-light guide: Beyond its supreme thermal stability, our borosilicate glass SUPRAX® 8488 offers low thermal expansion and zero water absorption allowing for precise light guidance along difficult environmental conditions.

Auer Lighting offers customized light guides as well as standard solutions. All light guides can be offered with our unique μ-treat technology further improving light distribution and color mixing. ■

LEDiL Introduces New Products

LEDiL announced the release of two new optic types; one for street lighting and another for interior architectural lighting; furthermore a modular linear multiholder for Tina and Tina2 lenses.

Just one example of LEDiL's new products - the Florence-1R-Maxi-WG which is available in different versions

Emerald-Maxi-A:
Emerald-Maxi-A is LEDiL's new area lighting optic with excellent illuminance uniformity over long distances. Emerald-Maxi-A is suitable for IESNA Type I Medium street lighting, retrofit street lighting applications, emergency escape lighting as well as pedestrian and security street lighting applications when tilted around 15°.

The lens features extremely wide batwing type two sided beam with a narrow cutoff on the transversal axis. It is optimized for high power domed multi-crystal LEDs.

Florence-1R-Maxi-WG:
E_{max} 680 lx LEDiL introduces a new addition to its Florence-1R family, the Florence-1R-Maxi-WG linear wall-grazing lens designed for interior architectural lighting. The Florence-1R-Maxi-WG has an asymmetric oval light beam pattern and a very narrow beam with high peak value to Maximize light falling into wall. The Florence-1R-Maxi-WG can be used as a single unit to highlight a certain zone of the wall or as continuous lamp line for overall wall washing illumination. It can be installed either to the ceiling or on the floor level and fastened with Florence-CLIPs. The 1R-Maxi-WG features uniform wall performance with optimal vertical depth and horizontal wideness and the design also allows the illumination to start already from the mounting level.

The Florence-1R-Maxi-WG is designed especially for high power LEDs. Linear optical design enables easy scaling for desired module lumen output.

Florentina:
LEDiL introduces Florentina, a new modular linear multiholder for Tina and Tina2 lenses. The holder can be equipped with additional dark light shade. Florentina-SHD provides an exceptional cutoff and completely hides away bright LED sources outside the beam.

Lenses are sold separately and easily installed by snapping them into the holder. Beam characteristics are completely customizable. For example, drop in couple of tight spot lenses to add that extra punch into your wide flood beam.

Release your creativity by combining different types of lenses from over 30 different optics available. ■

BQ Ceramics Launches Polar Light MC-PCB Technology at LpS 2014

At the LpS 2014, BQ Ceramics launched their Polar Light technology, which is the first ceramic coated MC-PCB with integrated heat sink and superior thermal conductivity, specifically developed for LED applications.

BQ Polar Light, with thermal via and ceramic coating at 1000 mA; 20 - 30 °C Cooler

BQ Polar Light allows LEDs to be placed in direct contact with the ceramic coated aluminum PCB. The concept provides superior thermal conductivity, whereby the heat generated directly underneath the High Power LEDs is very effectively dissipated to the ambient, resulting in a junction temperature that is up to 30°C lower than on a traditional MC-PCB.

The BQ Polar Light reduces the number of components in the light engine. Fewer components mean less material and fewer assembly steps. Combining these aspects, Polar Light enables applications that need more light emitted from compact spaces, offering design flexibility at lower cost.

The Polar Light technology also enables BQ Ceramics to be a very flexible partner for manufacturers of lighting applications to custom design, prototype and manufacture new products in small series and short time-to-market. ■

Square LED Heatsink Uses Cold Forging and Pin Fin Design to Enhance Performance

GlacialTech Inc., an experienced technology manufacturer, launched a new cold forged heatsink for 60W LED thermal solutions - Igloo FS127.

GlacialTech's Igloo FS127 square cold forged heatsink is designed for 60 W LED applications

Specifications:

- Type: Igloo FS127
- Dimension (mm): 127 x 127 x 63
- Weight (g): 750
- Material: AL1050
- Color: Silver
- Surface Treatment: Anodized
- Crafts: Cold forging
- Thermal Resistance (°C / W): 0.8980
- Surface Area (mm^2): 241166
- Reference design power (watts): 60 W

Pin Fin Design:
Using a pin-fin heatsink design for better airflow and surface area, the Igloo FS127 features a very efficient 0.89°C / W thermal resistance, appropriate for high performance LED applications up to 60W. Anodized surface treatment gives the Igloo FS127 corrosion resistance, scratch-resistance, and heat tolerance, making it more physically robust than untreated aluminum. Compared to straight fin designs, the pin fin Igloo FS127

performs well, regardless of orientation, making them ideal for lighting applications. A square heatsink shape accommodates square-type lighting fixture designs.

Low Thermal Resistance:
The Igloo FS127's low thermal resistance is achieved through a combination of cold forging as well as high performance materials. Cold forging produces heat sinks with better thermal characteristics and easier assembly than traditional die-casting or aluminum extrusion. With the AL1050 aluminum used in the Igloo FS127, thermal conductivity is 2.36 times better, compared to die casting; from 96.2 W/mK to 227 W/mK. Cold forging allows more complex shapes, and the Igloo FS127 is a one-piece design with no assembly required.

GlacialTech's Thermal Solutions:
GlacialTech's thermal solutions are designed with a focus on cost-effective performance, as well as weight and volume reduction. GlacialTech's LED lighting applications are designed to offer lightweight, space-efficient cooling at a great value. ■

Two New 480 V 40 W LED Driver Lines from Thomas Research Products

Thomas Research Products has introduced two new series of 40 W LED Drivers designed to operate on 347 V or 480 V mains. Thomas Research Products is a leading manufacturer of SSL power solutions.

Thomas Research Products' new 40 W LED drivers are designed for high voltage applications with 347-480 V

The new LED40W-HV series drivers are based on TRP's popular standard LED40W series models. Available in constant-current, dimming, and constant-voltage versions, the new High Voltage drivers work on any system from 347-480 VAC.

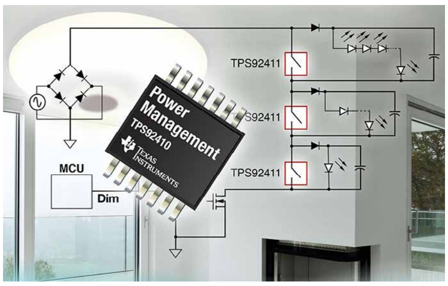
The LED40W-HL-HV series also operates at 347-480 V, but is designed specifically for hazardous locations. Type HL rated by UL, these drivers add thermal fusing and more robust cases.

This is the first time TRP has been able to provide such a mainstream product for 480 V input. The company's previous high input voltage drivers were only for 75 W and higher.

TRP's new drivers provide all the same features as their standard LED drivers and carry the company's standard 5 year warranty. ■

TI's New 450 V Linear Controller Simplifies Offline LED Lighting Design

Texas Instruments introduced a 450 V linear controller that simplifies current regulation of high-voltage LED strings. The TPS92410 controller integrates a multiplier and tunable phase dimmer detection, as well as analog dimming inputs and drive circuit protection functions to ease design of downlights, fixtures and lamps powered from an offline AC or conventional DC power source.



The TPS92410 operates over a wide 9.5 V to 450 V input voltage range

The TPS92410 operates over a wide 9.5 V to 450 V input voltage range and functions as a standalone high-voltage LED string current regulator or pairs with TI's TPS92411 floating switch to provide power in mains AC linear direct drive applications. Together, the TPS92410 and TPS92411 feature driver and LED circuit protection while providing an inductor-free, low LED current ripple lighting solution. The TPS92410 includes an analog dimming input pin with LED shutoff to provide easy light intensity control in intelligent, MCU-based light fixtures using the ultra-low-power MSP430F5172 microcontroller or SimpleLink™ ZigBee® CC2530 wireless MCU.

Key features and benefits of TPS92410
AC and DC applications Under-voltage lockout, MOSFET over-voltage protection and thermal fold back prevent driver and LED damage during fault conditions. AC applications with TPS92411 Compatible with legacy TRIAC and reverse phase dimmers in AC mains powered LED lighting applications. On-chip, internal multiplier produces very high power factor correction at greater than 0.95 with within plus or minus three percent line regulation.

About TI's floating switch architecture
TI's award-winning floating switch architecture achieves low LED current ripple performance which is comparable to switch mode power supply (SMPS) designs. The TPS92410 and TPS92411 require no inductive components for power transfer, eliminating cost and bulk, as well as simplifying the design. ■

Stadium Power - New LDP LED Power Supplies with Optional Dimming

Stadium Power, the leading UK provider of power supply solutions, has launched an unrivalled range of competitively priced LED drivers for a wide range of indoor and outdoor use in LED based lighting and signage applications.

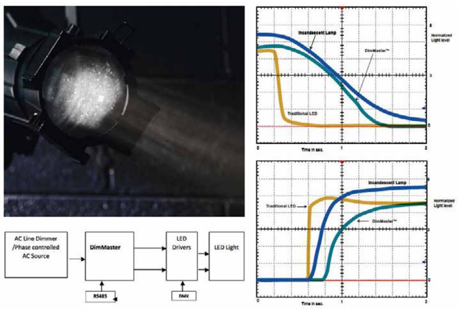
Stadium Power's LDP series of LED drivers can also be ordered in IP67

The new range includes the LDP series, offering 24, 36 and 48V constant current outputs over the range 25, 40 and 60 watts, with an optional dimming function via a signal from a dimming controller with PWM/1-10Vdc control signal and a 3 year warranty. Typical applications include industrial LED lighting and moving sign applications

Designated LDP25, LDP40 and LDP60 standard features include; wide universal AC input range from 90-305 VAC, active power factor correction (PFC) > 0.9, low inrush current <5 A, low profile, narrow footprint for ease of installation, low flicker for stable lighting output, continuous short circuit and over voltage protection, fully isolated plastic case and optional IP67 water proofing for outdoor or harsh environmental conditions. The LDP60 model may be specified as dual 30 W outputs or a single 60 W output. ■

CCI - Breakthrough Power Supply Technology for Phase Cut LED Dimming

Powered by CCI's new DimMaster™ LED phase-cut power supply technology, dimmable LED fixtures can now be developed to match the dimming performance of incandescent fixtures. Notably, the technology supports the transition of high performance lighting applications to LED, by seamlessly blending highly cost-efficient LED lamp fixtures into existing incandescent lighting arrays. Users can make this transition without investing in new dimmers or consoles, and without new wiring, because dimming is driven by the power supply within the LED lamp fixture.



CCI Power Supplies has released a new, patent-pending power supply technology for high performance, full-range LED dimming: DimMaster™ in action, configuration example and turn-off respectively turn-on curve comparison for incandescent lamps, conventional LED power supplies and the advanced DimMaster™ LED dimming technology

DimMaster™ LED power supply technology enables retrofitted LED's to match the full color and dimming spectrum of incandescent lighting for architectural, theater, church, stadium, studio, and other high performance lighting applications. The new technology enables CCI's power supplies to work with autotransformer, rheostat, thryristor and IGBT dimmers to support both older and newer dimming formats. ■

Soraa - New, 30% More Efficient Full Visible Spectrum MR16 LED Lamps

Soraa, the world leader in GaN on GaN™ LED technology, launched a complete new line of high performance MR16 LED lamps powered by the world's most efficient LED - the company's third generation GaN on GaN™ LED. Featuring the company's signature elements of full visible spectrum light, Soraa's new MR16 LED lamps feature a 30% improvement in efficiency, creating a no-compromise lighting solution for restaurants, retail, high-end residential, and office environments where superior light quality and smooth dimming are essential.

With the 3rd generation, Soraa improves the efficiency of their GaN on GaN™ technology based MR 16 LED Lamps by 30%

Soraa's new lamps have the company's Point Source Optics for beautiful, high intensity, and uniform beams; and unique Violet-Emission 3-Phosphor (VP_3) LED technology for perfect rendering of colors and whiteness. Utilizing every color in the rainbow, especially deep red emission, Soraa's VP_3 Vivid Color renders warm tones beautifully and accurately, and achieves a color-rendering index (CRI) of 95 and deep red (R9) rendering of 95. And unlike blue-based white LEDs without any violet/ ultra-violet emission, the company's VP_3 Natural White is achieved by engineering the violet emission to properly excite fluorescing agents including natural objects like human eyes and teeth, as well as manufactured white materials such as clothing, paper and cosmetics.

The perfect replacement for inefficient halogen lamps, Soraa's true retrofit sized MR16 LED lamps are fully dimmable and ideally suited for enclosed, non-ventilated, indoor and outdoor fixtures - a place where other LED lamps struggle to perform.
The LED lamps are available in 50 W to 75 W halogen equivalent light output; 10 degree, 25 degree, 36 degree, and 60 degree beam angles; 2700 K, 3000 K, 4000 K, and 5000 K color temperatures; and 95CRI and 85CRI. Plus, Soraa's 10 degree lamps work with its award-winning magnetic accessory SNAP System. With a simple magnetic accessory attachment, beam shapes can be altered and color temperature can be modified, allowing endless design and display possibilities. ■

Green Creative's Gen 4 A19 LED Lamp Offers Industry Leading Efficacy

Green Creative, the commercial grade LED lighting manufacturer proudly announces the launch of its new LED A19 9W lamp as part of the new Titanium LED Series 4.0. The A19 9W is one of five Green Creative lamps selected by the Illuminating Engineering Society (IES) for its prestigious 2014 Progress Report, which showcases unique and innovative products significant to the lighting industry.

Green Creative's new 60 W replacement lamp already meets the new and more stringent Energy Star® V1.1 requirements for standard A-lamps

This 60 W replacement meets the new Energy Star® V1.1requirements for standard A-lamps with an omnidirectional 300° beam angle and evenly distributed light intensity. Featuring a traditional A19 form factor, this dimmable lamp offers uniform light distribution while emitting 65% more lumens than what is required by Energy Star in the 135° to 180° degree zone.

Under the previous Energy Star requirements, A-lamps which were not fully omnidirectional could still receive Energy Star certification but were certified as non-standard A-lamps. Starting September 30th, the stricter V1.1 will no longer recognize non-standard A19s. After this date, any lamps qualified under the former standard will lose Energy Star certification.

Operating at 89 lpw in a Warm White CCT, the A19 9 W's efficacy exceeds Energy Star requirements by upwards of 60%. The natural A-lamp design makes this lamp a perfect retrofit choice for both incandescent and CFL lighting applications such as lamps with shades, down lighting and up lighting.

The new A19 9W turns on instantly, is fully dimmable, lasts 25,000 hours and is available in 2400 K, 2700 K, 3000 K and 4000 K CCT. Energy Star certification was expected by the end of September. ■

Cree Enters MR16 Halogen Lamps Replacement Market

Cree introduces the MR16 Series LED lamps with TrueWhite® Technology, that delivers the soft, diffused light of a traditional 50 W halogen MR16 lamp, and is designed for global compatibility with virtually all existing sockets.

Cree's Energy Star qualified MR16 replacement lamp combines CRI 92 with 580 lm and short payback time

With a suggested retail price of USD 25, Cree MR16 TrueWhite LED lamps consume up to 83 percent less energy and are designed to meet Energy Star® qualification to deliver a rapid payback of less than one year. This latest innovation is poised to replace the billions of MR16 lamps currently installed around the world by delivering an unprecedented combination of energy savings, color quality and compatibility.

Featuring a design that delivers greater than 580 lumens in conjunction with a proprietary lens, Cree MR16 Series TrueWhite LED lamps eliminate the glare commonly associated with 50-watt halogen MR16 lamps to deliver a soft, diffused light with category-leading color rendering index of 92. Cree MR16 Series TrueWhite LED lamps are dimmable and available in 15-degree spot, 25-degree flood and 40-degree wide flood beam angles in a 1.97-inch, ANSI-compliant form factor, allowing them to easily fit into existing tracks for a one-for-one replacement. ■

LED Lighting - New High Performance 24-Volt Tape Light & Versa Bar XLR

LED Lighting Inc., a primary resource for custom illumination solutions, has added 24-volt tape light and expanded their Versa Bar product line to include "XLR" (extra-long run). The Versa Bar XLR is offered in warm white (3000 K), neutral white (4300 K) and cool white (6250 K).

LED Lighting Inc. added new versions for 24 V and long life to their Versa Bar product line

Customers will experience numerous benefits including: half the current usage, cooler operating temperatures and the ability to specify longer runs per driver; the Versa Bar XLR has a maximum run of 32 feet per driver.

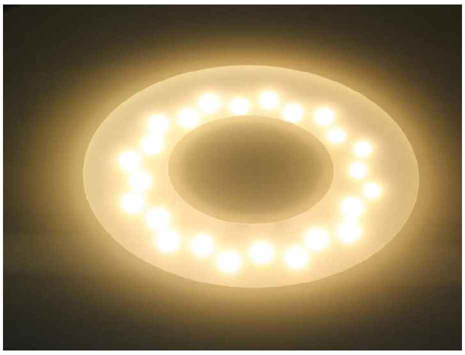
Most significantly, customers will experience minimal voltage drop, which ensures a more consistent light output from beginning to end. The importance of voltage drop for LED lighting is that an LED requires a minimum amount of current to accurately light. Less than the minimum current can cause an LED to flicker, or change the color and luminosity. This is more prominent in longer runs of LED tape light or Versa Bars.

In addition to these improvements, LED Lighting Inc. will offer 24-volt tape light, which features different cut points than 12-volt tape light. The 2014-2015 Catalog will incorporate all new product specifications.

LED Lighting Inc. will continue to stock 12-volt tape light and Versa Bars, but recommends that customers specify 24-volt tape light and the Versa Bar XLR to ensure optimum performance for all applications. ■

Data Link Launched Driverless Flush Mount Ceiling Lamp at LpS 2014

Our company's mission was to develop and produce an affordable and durable LED down light that can compete with other commercial products of this type available in the marketplace. As a result of our efforts we presented a series of lamps made in a unique patented planar technology. From the very start we opted for the robotic automatic production line concept with minimum human involvement. This product has been designed with the intention of being assembled on an automatic robotic line which can produce more than 400 units per shift.



Data Link's new driverless flush mount ceiling lamp is produced on a robotic automatic production line with minimum human involvement

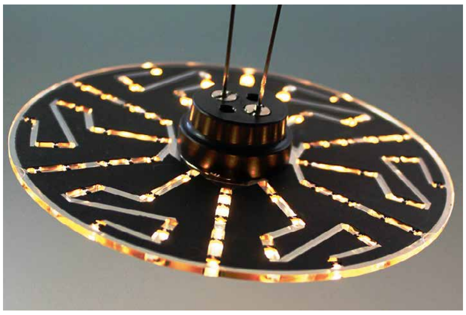
LED Ceiling Lamp characteristics:

- LCL230R-AC drastically reduces energy consumption compared to incandescent or CFL lamp
- LCL230R-AC provides a large luminous flux of at least 1400 lumens, while its consumption is only 16 W
- This lamp (light fixture) has a real lifespan of over 60,000 hours
- LCL230R-AC is especially suitable for extended number of power cycles and therefore suitable for staircase and hallway lighting
- It is suitable for flush mounting to plasterboard and suspended ceilings or alternatively can be surface mounted using the bracket supplied
- The lamp has a very pleasant white light suitable for domestic dwellings and residential market, with color temperatures available from warm white 2700 K to neutral white 4000 K depending on the application
- LCL230R-AC lamp reduces maintenance costs in buildings due to the high reliability and long life
- This lamp has outstanding thermal management due to the large surface cooler that allows the low LED junction temperature
- LCL230R-AC lamp is thermally protected, which means that at higher ambient temperatures it reduces the intensity of light and prevents overheating of the LED and shortening of the lifespan

The incoming AC LED technology has enabled that this lamp has a minimum of components and having no electronic parts that are susceptible to aging. Additionally, this lamp can endure millions of power cycles and has a very long life. Flush Mount Ceiling Lamp is the low energy alternative to incandescent and Compact Fluorescent bulbs. It is designed for hallways, staircases, bathrooms, lounges or any other area that needs pleasant and high efficiency lighting. ■

Bayer Polycarbonate Enables Precise Manufacturing with Printed Electronics

An innovative, extremely flat LED lamp from EDC GmbH opens a whole new range of possibilities for energy-efficient light design. The "F|limyé Flat," for example, is perfectly suited to those situations where there is little space for lamps or when special design solutions are needed. Based in Langenhagen, near Hanover, the company manufactures this product using Makrolon® OD2015, a special transparent polycarbonate from Bayer MaterialScience.



A flat substrate made from Makrolon® polycarbonate from Bayer MaterialScience allowed EDC GmbH to make an innovative, extremely flat LED lamp that opens up whole new possibilities for energy-efficient lighting concepts. At just 1.8 mm, it is as thin as a CD and can be round or square

The special feature of the LED lamp is a flat substrate made from this high-performance plastic. At just 1.8 mm, it is as thin as a CD and can be round or square. During injection molding, tiny dimples 1.4 mm wide and 1.2 mm deep are incorporated into the substrate. These then take the numerous little LEDs. The polycarbonate's outstanding reproduction accuracy enables much higher precision in forming the dimples than can be achieved with other transparent plastics.

Breakproof and dimensionally stable

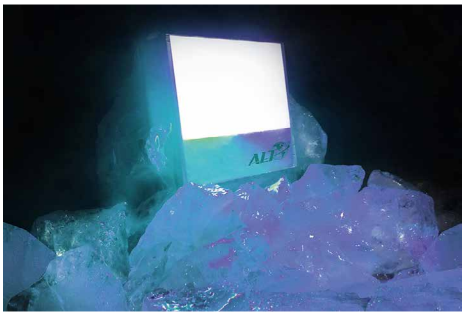
This material grade was specifically developed for light conductors, optical systems and lenses, and provides a very high level of light transmission even with greater coating thicknesses. It is also shatterproof and boasts excellent dimensional stability across a wide range of temperatures. This enables the finely structured lights to be manufactured with great precision.

ECD has opted not to use conventional circuit board technology in the construction of the LED lamp. All of the electronic elements required to operate the tiny LEDs, such as resistors and conductor tracks, are thinly printed onto the transparent substrate. This is where the excellent print quality of Makrolon® OD2015 really pays off. It is also possible to add microstructures for routing the light. This special design even allows light to escape at the edge – an additional optical effect that has great appeal.

The lighting disk can also be fitted with flat auxiliary lenses or integrated optical systems that focus or diffuse the LED light as required. Diffusers, lens plates or reflectors can be combined or integrated to achieve uniform illumination. This gives rise to diverse potential applications for "F|limyé Flat" in living areas and kitchens, designer lights, and shop and office lighting. Being lightweight, the lamp is also ideal for mobile applications including cars, motor homes and the aviation industry. ■

ALT Releases Ultra Deep Temperature Resistant Products

Before the "Ice Bucket Challenge" craze, ALT products had already been known to feature products that work in the harshest environments. Remember the PAR38 lamp cooking in boiling water? This time, the challenge is for the lamp to work and operate in ice cold water.



ALT's industrial plus versions of the Metis A55 bulb, Orion T8 tube, Asteria PAR38/30, and the Lodestar floodlight series can withstand extremely cold temperatures

The standard ALTLED Lodestar Floodlights are designed to work in minus 40 degrees Celsius temperature, but the industrial plus version may be IP68 and work in -65°C, a feature most (if not all) other manufacturers have not been able to achieve yet. These lights work in extremely cold freezers or other extremely cold environments, such as labs, polar indoor or outdoor regions.

The -65°C (-85°F) lamps include Metis A55 bulb, Orion T8 tube, Asteria PAR38/30, and the Lodestar floodlight series. ALT provides a full line of indoor and outdoor products for various applications, extreme conditions, stringent requirements. ■

New Hi-Flux LED Slim Strip Lights for Architectural and Accent Lighting

LEDtronics® announces its new series of Hi-Flux LED Slim Strip Lights that come in a sealed enclosure with water-clear lens and are IP68-certified waterproof. With a great-looking strip illumination that provides even lighting without the buzzing and flickering that afflicts fluorescents, the TBL4520 series offers versatility in applications such as passenger interiors; task lighting, under cabinets, concealed lighting, edge lighting, cubicles, marine recreation areas, as well as coolers, freezers, retail store displays.

The TBL4520 strip lights come in a variety of 6, 12, 24 and 48 inch lengths and three CCTs

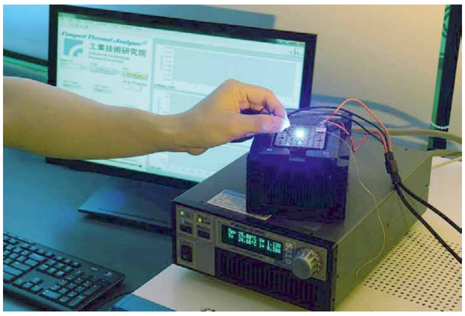
The construction of a clear polycarbonate cover over the LED tube provides increased protection and shielding against many environmental effects, allowing its placement in locations where typical lights would be more vulnerable to the elements. The sturdy aluminum bar offers a secure and easy installation, along with the easy-to-use mounting clips.

The TBL4520 series strip lights come in a variety of 6, 12, 24 and 48 inch lengths to fit in many different locations, tight enclosures and spaces. Mounting clips that snap onto the back of the sturdy aluminum bar, and VAC-to-12 VDC transformers are sold separately. Three color temperatures are available: Warm White (2500 K to 3000 K), True White (5000 K to 5500 K) and Cool White (8000 K to 9000 K). Each LED strip offers a wide viewing angle of 90 degrees.

These LED Strip lights produce almost no heat, and require 80%-90% less operating power than equivalent incandescent or fluorescent lighting, making them as friendly to the environment as they are to the operating budget. ■

ITRI Introduces ICTA Reducing LED Thermal Testing Time by More Than 90%

Industrial Technology Research Institute (ITRI), Taiwan's largest and one of the world's leading high-tech research and development institutions, is pleased to introduce In-Line Compact Thermal Analyzer (ICTA) Technology. The world's leading automatic thermal analyzer, ICTA offers a measurement speed of 12,000 LEDs per hour, reducing each LED's component thermal resistance testing time to 0.3 seconds. This is 2,000 times faster than the traditional lab method where only six components can be measured per hour. ITRI will receive a 2014 R&D 100 Award in November for this breakthrough technology in the "Imaging" category.



ITRI's new In-Line Compact Thermal Analyzer (ICTA) offers a measurement speed of 12,000 LEDs per hour, reducing each LED's component thermal resistance testing time to 0.3 seconds

Thermal performance has always been the primary factor impacting the life and light quality of LEDs. ICTA Technology is the most powerful, cost efficient and high performance thermal analyzer when compared to other LED thermal testers available today -- greatly reducing the defect ratio of LED illumination products. While decreasing LED testing time, ICTA improves production yield, performance and lifespan of LED devices such as LED bulbs, mobile phones, TV, laptop display backlight, etc. This innovative technology has a high-speed temperature sensitive parameter (TSP) measurement technique that could reduce LED testing time by more than 90 percent, thereby improving the efficiency of thermal structure analysis. These attributes lead to more reliable LED devices for end-users. In power semiconductor devices, ICTA can be used to solve thermal-induced stress, enabling innovative package design and material property identification or facilitating lifespan estimation.

Up-to-now, measuring LED thermal resistance has been complex, time-consuming and could only take place in the laboratory at the product design stage. With ICTA, manufacturers can now screen defective products on the production lines in real-time, optimizing production processes, increasing efficiencies to significantly lower LED lighting defect rates. This technology ensures, creating higher quality and more stable LED lighting products, for the delivery of best quality products to end-users, and finally, wider adoption of LED technology worldwide.

ICTA is the most efficient thermal analyzer, offering the critical thermal characteristics such as junction temperature and thermal resistance for semiconductor devices, including LEDs, High-Electron-Mobility Transistor (HEMT), Metal-Oxide-Semiconductor Field-effect Transistor (MOSFET), and Insulated-Gate Bipolar Transistor (IGBT).

ITRI has given the first technology transfer and patent licensing contract to leading global manufacturer MPI Corporation. The company is engaged in technology cooperation that has yielded the world's first transient thermal structure and in-line thermal resistance analyzer. This equipment is expected to get into the mass production stage by the end of 2014, which will both satisfy R&D and production authentication requirements. ■

Gigahertz-Optik - Launched New Spectroradiometer at LpS 2014

With regards to photometric and colorimetric specifications, LED binning is a great challenge in light measurement technology due to the number of units. In addition to the highly accurate measurement values, the measurement time is also a significant factor. This does not only refer to a shortest possible measurement time and fast data transfer for high clock speeds. Precise synchronization of the measurement device with the system process is also of great importance. With the new BTS2048-VL, Gigahertz-Optik offers a spectral light and color measurement device that meets all the requirements in LED measurement technology in industrial manufacturing processes.

Gigahertz-Optik's new BTS2048-VL meets all the requirements in LED measurement technology in industrial manufacturing processes

Some of the outstanding features of this new light meter include:

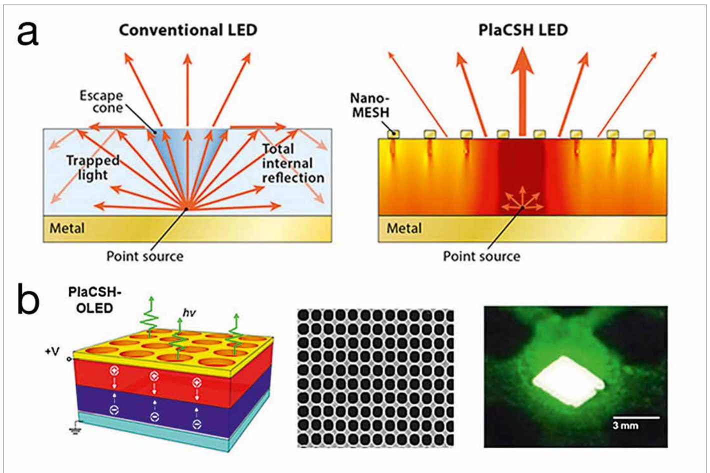
- Electronic shutter for measurement times between 2μs and 4s
- Back thinned CCD array with high sensitivity
- Fast data read out – 7ms for a complete data record via LAN interface
- Precise measurement data in photometric and colorimetric quantities
- Standard filter wheel (4 positions: open/closed/OD1/OD2)
- Trigger inputs and outputs for timed synchronization
- High calibration stability through a COS diffuser window instead of flexible light guides
- Compact and sturdy design for flexible system integration
- Software development kit for easy software implementation

Gigahertz-Optik offers a wide range of complementary products for this cutting-edge measurement device. These include integrating spheres, luminous intensity attachments and goniometers. These complementary products enable adaptation of the measurement device to the common measurement geometries.

The powerful user software makes the BTS2048-VL an ideal, high-quality spectral light meter for applications in a measurement laboratory. ■

Nanotechnology May Lead to Better, Cheaper LEDs and OLEDs

Princeton University researchers have developed a new method to increase the brightness, efficiency and clarity of OLEDs, which are widely used on smartphones and portable electronics as well as becoming increasingly common in lighting. Using a new nanoscale structure, the researchers, led by electrical engineering professor Stephen Chou, increased the brightness and efficiency of OLEDs made of organic materials (flexible carbon-based sheets) by 57%. They also report their method should yield similar improvements in LEDs made in inorganic materials used most commonly today.



(a) Princeton researchers have used their expertise in nanotechnology to develop an economical new system that markedly increases the brightness, efficiency and clarity of LEDs, which are widely used in smartphones and other electronics. The illustration demonstrates how a conventional LED structure traps most of the light generated inside the device; the new system, called PlaCSH, guides the light out of the LED. (Illustration courtesy of Stephen Chou et al.) (b) PlaCSH has a layer of light-emitting material about 100 nm thick that is placed inside a cavity with one surface made of a thin metal film (shown on the left.) The key part of the device is a metal mesh (center) with incredibly small dimensions: it is 15 nm thick; and each wire is about 20 nm in width and 200 nm apart from center to center. An image of the experimental LED is shown at right. (Images courtesy of Stephen Chou et al.)

The method also improves the picture clarity of LED displays by 400%, compared with conventional approaches. In an article published online in the journal, Advanced Functional Materials, the researchers describe how they accomplished this by inventing a technique that manipulates light on a scale smaller than a single wavelength.

"New nanotechnology can change the rules of the ways we manipulate light," said Chou, who has been working in the field for 30 years. "We can use this to make devices with unprecedented performance."

A LED, or light-emitting diode, is an electronic device that emits light when electrical current moves through two terminals. LEDs offer several advantages over incandescent or fluorescent lights: they are far more efficient, compact and have a longer lifetime, all of which are important in portable displays.

Current LEDs have design challenges; foremost among them is to reduce the amount of light that gets trapped inside the LED's structure. Although they are known for their efficiency, only a very small amount of light generated inside an LED actually escapes.

"It is exactly the same reason that lighting installed inside a swimming pool seems dim from outside — because the water traps the light," said Chou, the Joseph C. Elgin Professor of Engineering. "The solid structure of an LED traps far more light than the pool's water."

In fact, a rudimentary LED emits only about 2 to 4% of the light it generates. The trapped light not only makes the LEDs dim and energy inefficient, it also makes them short-lived because the trapped light heats the LED, which greatly reduces its lifespan.

"A holy grail in today's LED and OLED manufacturing is light extraction," Chou said. Engineers have been working on this problem. By adding metal reflectors, lenses or other structures, they can increase the light extraction of LEDs. For conventional high-end, organic LEDs, these techniques can increase light extraction to about 38%. But these light-extraction techniques cause displays to reflect ambient light, which reduces contrast and makes the image seem hazy.

To combat the reflection of ambient light, engineers now add light-absorbing materials to the display. But Chou said such materials also absorb the light from the (O)LED, reducing its brightness and efficiency by as much as half. The illustration demonstrates how a conventional LED's structure traps most of the light generated inside the device; the new system, called PlaCSH, guides the light out of the (O)LED.

The solution presented by Chou's team is the invention of a nanotechnology structure called PlaCSH (plasmonic cavity with subwavelength hole-array). The researchers reported that PlaCSH increased the efficiency of light extraction to 60%, which is 57% higher than conventional high-end organic LEDs. At the same time, the researchers reported that PlaCSH increased the contrast (clarity in ambient light) by 400%. The higher brightness also relieves the heating problem caused by the light trapped in standard (O)LEDs.

Chou said that PlaCSH is able to achieve these results because its nanometer-scale, metallic structures are able to manipulate light in a way that bulk material or non-metallic nanostructures cannot.

Chou first used the PlaCSH structure on solar cells, which convert light to electricity. “From a view point of physics, a good light absorber, which we had for the solar cells, should also be a good light radiator,” he said. “We wanted to experimentally demonstrate this is true in visible light range, and then use it to solve the key challenges in LEDs and displays.”

The physics behind PlaCSH are complex, but the structure is relatively simple. PlaCSH has a layer of light-emitting material about 100 nm thick that is placed inside a cavity with one surface made of a thin metal film. The other cavity surface is made of a metal mesh with incredibly small dimensions: it is 15 nm thick; and each wire is about 20 nm in width and 200 nm apart from center to center. (A nanometer is one hundred-thousandth the width of a human hair.)

Because PlaCSH works by guiding the light out of the LED, it is able to focus more of the light toward the viewer. The system also replaces the conventional brittle transparent electrode, making it far more flexible than most current displays.

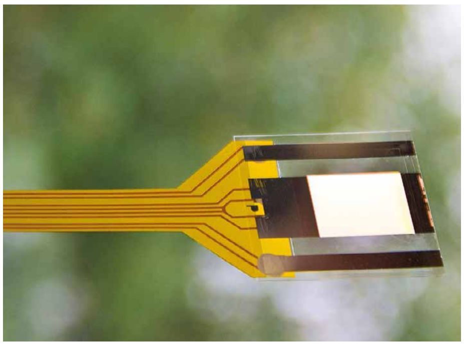
Another benefit for manufacturers is cost. The PlaCSH organic LEDs were made by nanoimprint, a technology Chou invented in 1995, which creates nanostructures in a fashion similar to a printing press producing newspapers. “It is cheap and extremely simple,” Chou said.

Princeton has filed patent applications for both organic and inorganic LEDs using PlaCSH. Chou and his team are now conducting experiments to demonstrate PlaCSH in red and blue organic LEDs, in addition to the green LEDs used in the current experiments. They also are demonstrating the system in inorganic LEDs.

Besides Chou, the paper’s authors are Wei Ding, Yuxuan Wang and Hao Chen, graduate students in electrical engineering at Princeton. Support for the research was provided in part by the Defense Advanced Research Projects Agency and the Office of Naval Research. Chou recently was awarded a major grant from the U.S. Department of Energy to further advance the use of PlaCSH as a solution for energy-efficient lighting. ■

Printing Process of Metal Contacts for Reliable Contacting of Flexible OLEDs

A significant growth is predicted for the market of flexible devices. The topic “Wearables”, namely intelligent, wearable systems with several useful and funny features is currently one of the major discussion topics. To enjoy more comfort, exceptional designs and higher functionality manufacturers and users ask for flexible electronic devices, like displays, lighting elements or circuit boards.



Fraunhofer FEP works on cost-effective system solutions for flexible devices and presents results at Plastic Electronics 2014

Although research and development groups have already made considerable progress in this field, not all challenges could be solved so far. Various topics are subject to further development, e.g. materials, processes, machines as well as system integration.

Fraunhofer FEP provides a roll-to-roll process line which enables the application of organic materials for OLED (organic light-emitting diodes), OPD (organic photodiodes) or OPV (organic photovoltaic) on flexible substrates in one complete technology. The process includes the structuring, automatic inspection of the initial substrates, the vapor deposition of the organics and, finally, the encapsulation of the coated films or glasses.

Organic electronics certainly require flexible electrical contacts. Therefore, Fraunhofer FEP implemented an additional printing process of metal contacts for the reliable contacting of, for example, large-area flexible OLED on metal, polymer and thin glass substrates. In cooperation with printing paste manufacturers and other suppliers like machine manufacturers, adhesive manufacturers and encapsulation film suppliers, scientists are now able to develop optimized products for required process steps under production conditions..

Dr. Jacqueline Brückner, Project Manager Surface Analysis for the roll-to-roll organic technology, says: “Our customers have different requirements to design and mechanical stability of devices. With our know-how and our process equipment we provide a unique development platform for all these demands.” ■

Tech-Talks Bregenz - Prof. Jiangen Pan Everfine, Founder & CTO

Prof. Jiangen Pan

Prof. Jiangen Pan is the Founder, Chairman and CTO of EVERFINE. He is also Vice Chairman & Secretary-General of Subcommittee 3 on Measurement of Light and Radiation of the Standardization Administration of China, a member of the General Expert Group of National 863 Program on Solid State Lighting and the Chairman of CIE TC2-74 (goniospectroradiometry of optical radiation sources). Prof. Pan has engaged in technology research and instrument development on photometric, colorimetric, electronic and EMC test & measurement since 1985. In 2010, Prof. Pan was granted the “National Outstanding Innovation Award” and awarded as ”National Excellent Scientist”.

With ever-increasing demands on measurement equipment, it is becoming essential to meet user needs by providing combined solutions, which address optical, electrical and thermal issues. Prof. Jiangen Pan CTO, Founder and Chief Scientist at Everfine Institute of Optoelectronics, provided valuable insights on new compact solutions for LED measurements, his views and contributions towards global standards and how he works in his "thinking laboratory".

LED professional: Professor Pan, you are the Vice Chairman & Secretary-General of Subcommittee 3 on Measurement of Light and Radiation within the Standardization Administration of China. Could you tell us about the main aims and goals of this subcommittee?

Professor Pan: This committee is under the standard administration of China. I am the Secretary and Vice chairman responsible for the standardization in China and this work is coordinated with CIE division 2. They have made a lot of technical reports and standards about LED measurements and test methods for LED quality. In China, we have the sub committee and we research the measurement methods for LED products and we also promote our research results and make recommendations to the CIE. Some experts from China have joined the standardization work in the CIE. We also translate CIE documents to Chinese and these are accepted by the standard administration of China.

LED professional: So what you're saying is that it goes in both directions. The parts that come from the CIE are taken over by the Chinese regulations and you also put your findings in the general regulations of the CIE. Is there a broad common understanding about the importance of different parameters or are there differences in findings for different research areas?

Professor Pan: Usually we coordinate well and we follow CIE very closely. Sometimes China may differ in application areas because the application industry in China evolves very fast and we have a very strong manufacturing system so we may need something new. But CIE is an international organization with many nations and to vote for a standard is not easy.

LED professional: Could you tell us about the General Expert Group of National 863 Program on Solid State Lighting? What is it and what are the responsibilities of this group?

Professor Pan: The government coordinated this and we have 11 top Chinese scientists in this group. We led the development of the solid-state lighting industry and we determined the future of SSL, supported by the government, who gave a lot of funding for the project. We selected research teams in China and then companies, institutes and universities joined the project. We designed challenging topics and criteria and then we selected research teams. Experts were always invited by many organizations, so we also joined the work of CSA, ISA and CIES, which is the Chinese national committee for CIE.

LED professional: You are also CEO and Chief Scientist at Everfine. Could you give us a short overview of the company?

Professor Pan: Everfine is mainly involved in measurement equipment for the LED and the lighting industry. We have a lot of measurement equipment not only for photometry but also electronic measurement devices, including EMC and power supply. We have a very broad product portfolio compared with other competitors in Europe, the USA and Japan. The company was founded in 1993 and it was accepted by the stock exchange in 2012. We have more than 500 employees mainly in China, more than 10 times that of our competitors in other countries! We also have divisions in Taiwan and San Francisco.

LED professional: That's very impressive! Is it correct to say that you also founded the company and brought in the technologies?

Professor Pan: My major topic was in optical instruments and my specialty also covers electronics and software. So I have a background in mechanics, optics, electronics and software technologies. After leaving university, I started my research institute and then the company. Everything started from research. My main work, so far, has focused on technical issues. I love to learn new technologies and design on my own and I've now joined the activities of international standardization.

I also studied Management and Economics at university. So I know how to run a business and how to encourage a team. I was a guest researcher at NIST and my colleagues always asked me how I could run a company while working at NIST. The way I do it is: I have a qualified management team in my company and they have their positions and their jobs and work well with one another. My method is that "if the majority agrees it means that I agree". It is quite a democratic process! Teamwork is very important for management especially because I want to have enough time to focus on my research and technologies. I have three assistants and their job is to write down my inventions and file patents.

LED professional: How many patents have you filed?

Professor Pan: We have filed more than a hundred patents. More than half of this industry worldwide.

Figure 2: **Prof. Pan and Siegfried Luger agree that the motto of the LpS 2014 - Design and Engineering for Future LED Lighting Systems - is the key for success on the market**

LED professional: Where do you get the inspiration?

Professor Pan: I find my way in my "thinking laboratory". Sometimes my colleagues want to do experiments in a laboratory but I say that you have to prepare everything in your mind first. If the design is not good and if your job is not well done, experiments may give you a false result. Experiments might be wrong. So we have to think it over. If your logic is strong enough and you have good background knowledge, it will help you very much. My own deep physics background helps me to think of designs and other things in my "thinking laboratory". It is very important and low cost!

LED professional: You have a very deep insight into technology and research. With the LED, some requirements and measurements change dramatically and new regulations require that you combine the electronic measurements with the light measurement. What is your experience with this trend?

Professor Pan: This is a very important question. I have found that many companies say they are "professional" so they only research the optics or the electronic parameters or only measure thermal issues. I think these are strongly related to each other and if you can see all these problems, you can combine them and find a solution for all the aspects - not just optics but also electronic and thermal. We face many challenges for LED measurement because changing the temperature means thermal dependence and we have to control the electrical parameters. So we need an overall solution. In the past when we measured the thermal parameters we forgot about the optical parameters and output optical power, because this power doesn't influence thermal parameters. The thermal parameters are only from the electronic power converted to heat and therefore influencing the LED. So we have to measure the optical power and electronic power and then analyze its thermal performance. It should be a compact solution. So I think the total solution is very important and this is the new challenge for the measurement of LED performance.

LED professional: There are different demands on LED products based on their application. Can the new goniospectroradiometer be used both in research and production lines? How are demands different in these two areas?

Professor Pan: I have given two recommendations to the CIE. The first one is that we need a new document for measurement of LED luminaires because these are quite different to the traditional approach. The traditional is only the fixture but the LED combines it, also including the lamp itself. So the measurement method should be changed. The other recommendation is that I think now we should not only measure the luminance intensity distribution of the LED. We also have to measure its spectral qualities. For traditional light, usually the spectrum distribution in different angles is the same. But for LED it is not. The color is not uniform. So we have to measure it. We have many solutions for LED measurement and finally I have found a new solution that can solve all the optical measurement problems. So I recommended that the CIE have such a new document. In 2011, the CIE agreed to have such a new technical quantity and I was selected as a chair for this area. A draft has now been prepared and we hope

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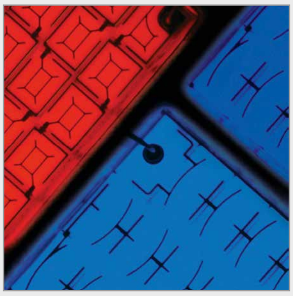

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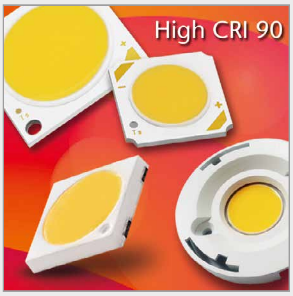

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LEDs with high CRI > 90 (color rendering index) can help fixtures to reveal colors faithfully and close to natural light source. Lextar's high CRI LED packages, 3014, 5630, 3030, 5050 and COB, are designed for both commercial and residential applications, such as candle light, bulb, downlight, tube, par30 and par 38. The entire CRI 90 series offer various color temperatures of 2700K, 3000K and 4000K, with high efficiency performance of 110 lm/W. Lextar's high CRI LEDs add values and quality to your lighting products.

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Figure 2:
The split view of an LED lamp shows the different components that are interacting and have to be taken into account for testing and measurement tasks

Figure 3:
The HAAS-3000 spectroradiometer was launched at the LpS 2014. It is the latest innovative development out of the broad range of Everfine's measurement tools

that the document will be published in 2015-2016. This is a very important area because if we have the goniospectralradiometric information, we have all the information of a luminaire.

LED professional: With measurement requirements there are always different and sometimes contradictory needs based on application and user needs. What are the contrary requirements depending on the users? And how are they overcome or met?

Professor Pan: The spectroradiometer was widely applied both in industry and in the laboratory but for laboratories there is a very high accuracy requirement and the stray light level is the key performance for the spectroradiometer. We have a total solution for this performance. We combine the modified NIST correction method and band pass filter wheel technology. This was also in my presentation at LpS 2014. We have many application groups and the performance is almost equal to the double monochromator level. This kind of high accuracy device can also be applied in production lines because the measurement speed can also be very fast! I think the high accuracy array spectroradiometer can be widely applied in the LED industry and the laboratory.

LED professional: Is there any significant trade off of other parameters?

Professor Pan: I think the cost is a little higher for these spectroradiometers but this is the advantage of a Chinese company, because we have a lot more customers. In China we have more than 10,000 LED companies! So we have a lot of opportunity to have bigger engineering teams with more experience, more skills and more opportunity to invest and develop our technology. Our research costs and our manufacturing costs can be lower and our performance-to-price ratio can be very competitive.

LED professional: A European company told us that they wanted to buy a sphere for measurement modules and they told us that only Everfine was able to provide it. They wanted a maximum diffused reflection and they said you used a nano-technology approach. Is that right and what is this approach/coating?

Professor Pan: The most important thing is that the coating should be non-selective with almost ideal Lambertian performance and it should be stable for a long time. Because inside the sphere, if the reflectance changes a little, the output of the signal changes a lot so the stability is very important. It was not nano-technology but it is special for Everfine.

LED professional: You mentioned new standards and global drafts that you are involved in. What are the key parameters defining the measurement market and how will new standards affect the businesses?

Professor Pan: .I think the standard for existing products is not enough and the international societies are fighting for that. For new applications, the LED market and its applications are just at the beginning because everything we see is only replacing traditional lights. Actually, this is not a new LED application. We have to move forward. In China, as the expert group, we promote innovative applications for LEDs and for new innovative applications; we need new standards, methods and measurement equipment.

LED professional: 2015 is the International Year of Light. What are your expectations for it and are there any national initiatives in China?

Professor Pan: CIE and other key organizations have joined this initiative and China has also joined. There will be many activities happening and my company will open our laboratories to the public for a period of time. We are now promoting this and hoping that more organizations will open labs to the public to tell them about the lighting industry. This could be quite meaningful for the general public.

LED professional: You are at the LED professional Symposium +Expo for the first time. You presented a paper and also have a booth for your company, Everfine. What are your impressions?

Professor Pan: I feel that Bregenz is a beautiful place and the LpS has been organized very well with so many professional people here. This is very important. Many key scientists and engineers are gathered here and some of them are very active in CIE and IEC and I think the attendees are very high level and professional. This is very good.

LED professional: Professor Pan, thank you very much for your time and this very interesting talk.

Professor Pan: Thank you. ■

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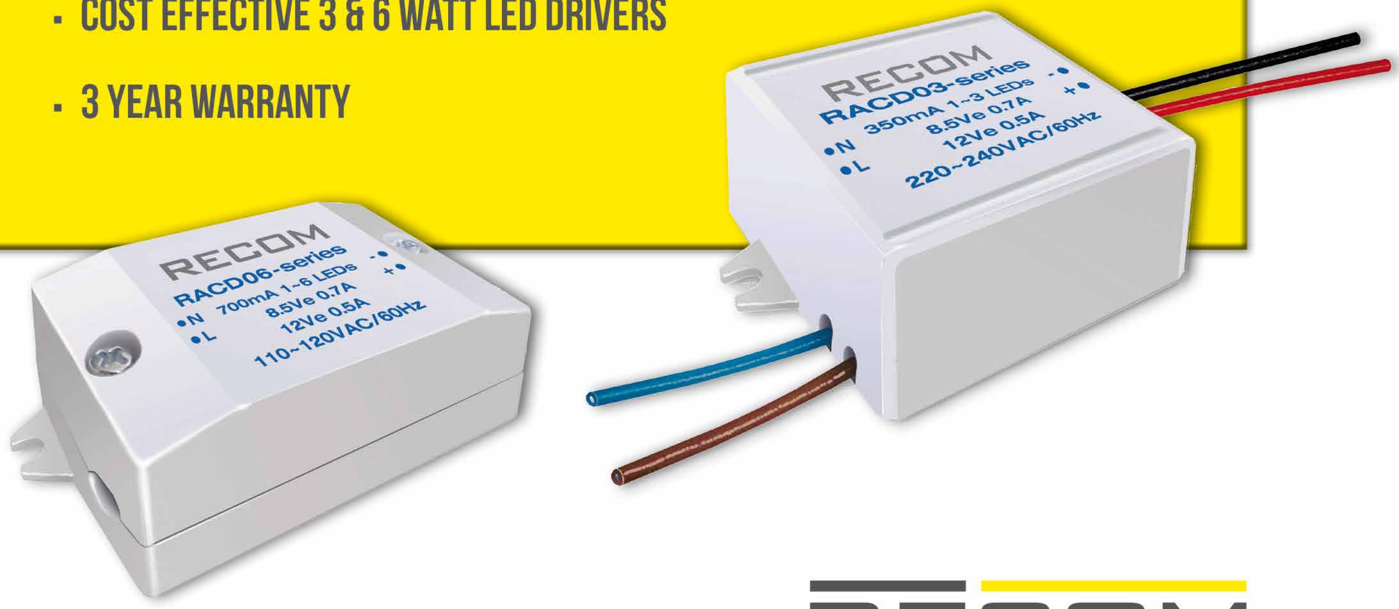

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LpS 2014 – Fostering the Spirit of Innovation and Engineering Arts

After three exciting days full of informative lectures and interactive workshops, the 4th LED professional Symposium +Expo closed its doors on October 2nd, 2014. Katharina Fink, Amrita Prasad, and Arno Grabher-Meyer from LED professional write about highlights, product launches, latest trends in LED and OLED technologies at the exhibition and in the workshops and lectures as well as presenting facts and figures about the event.

The LED professional Symposium +Expo 2014 (LpS 2014) has established itself as an international point of reference for technical designers, manufacturers and lighting professionals dealing with LED lighting modules and systems. This year it attracted over 1,100 partakers from 43 countries. 45% of all attendees came from technical areas like Research & Development, Engineering / Project Management, Design Engineering/Product System Design and Manufacturing / Application Engineering. A further 15% were from the Executive/ Corporate management level.

In total, 60% of the participants can be deemed as decision makers, responsible for the technologies and products used for future LED lighting modules and systems.

Close to 100 exhibitors from all over the world used the LpS as a platform to introduce their latest products, services and innovations to the technically adept audience. 12 companies decided to use the LpS as a platform for their European or global product launches, including LEDs, optics, thermal management products and measurement equipment.

Attendees, authors and exhibitors alike commended the high quality and technological focus of the event (see "Voices from LpS 2014"). The initiation of new ideas was brought about by discussions generated by the fifty-eight lectures, five workshops and two tech panels. The conference program covered topics dedicated to integrated designs of LED and OLED lighting systems: trends and visions in future LED lighting systems, materials and manufacturing, light sources, reliability and lifetime, engineering of LED optics, electronics and smart lighting as well as design with LEDs and OLEDs.

Figure 1: **The keynote speeches at the opening ceremony by Prof. Reine Karlsson, Mark McClear and Prof. Tran Quoc Khanh were well received**

Figures 2-4:
Dr. Peter Bodrogi was presented the LED professional Scientific Award in a ceremony just before the keynote speeches. Discussions with the Keynote speakers took place after their talks. Here we see Prof. Tran Quoc Khanh explaining his theses and findings in more detail

Opening and Keynote Speeches

This year, in accordance with the new structure of the conference, there were four keynote speeches; three at the beginning of the conference and one as an opening for the workshops. The number of people that attended the opening surpassed all expectations. The three top class experts holding the opening-keynotes were probably one of the reasons for the large crowd. Another factor was most likely the announcement of the Scientific Award winner. After a few words of welcome, event Director, Siegfried Luger, announced the winner as being Dr. Peter Bodrogi from the Technical University of Darmstadt for his paper titled: "New Binning Strategy for White LEDs to Improve the Color Quality of Interior Lighting". Mr. Luger and Stoil Kordev, General Manager of Optonica LED and Scientific Award Sponsor, handed Mr. Bodrogi the LED professional Scientific Award Trophy and a check for EUR 3,000.

"Intelligent Lighting for People" was not only the title of Prof. Reine Karlsson's keynote but Lighting for People is also the public website and slogan of the SSL-erate project, part of the 7th EU framework program for research and technological development. In his speech, Prof. Karlsson explained why LED applications have only made use of a minor part of the possible added user value and business development potential. He also clarified how Lighting for People will help to enhance the added user and business value by promoting solutions that are better for people's health and well being, and also accentuate green business development. He pointed out that 95% of the value chain would be created in lighting solutions and only 5% in light sources. He also emphasized the importance of "providing the right light, in the right place, at the right time, for each and every person, and avoiding glaring, ugly, disturbing, useless light". He showed that before the SSL era, the freedom for action to fulfill these requirements was very limited. He also warned that this freedom of action could be used or misused. Probably the most dangerous kind of misuse, from a business perspective, is the opportunity to cheat by using the enthusiasm for a new technology to sell poorly implemented lighting products and systems that could even cause harm. Finally, he asked the audience to be innovative and to create meaningful light. Two examples he used were, "…activating light when there is a need to wake up…" and "…soothing light when you want to calm down."

Representing the Industry, Mark McClear, Vice President of Application Engineering at Cree, talked about what influences the SSL market and technology. In his speech, "The Changing Role of Components in SSL Systems", he pointed out that at least three issues had influenced the LED lighting market. One was "Free Epi", a term he used for the over-supply of LEDs. Another were the global repercussions of disasters like Fukushima that drove the creation of a supply chain that would not have made economic sense otherwise. The third, he labeled as "Distractions on the Way", which he explained as meaning that people will try anything once. Some technologies work but don't make economic sense; others don't work at all. He showed how improved LED quality, power and efficiency

Figure 5:
Animated activity in the exhibition hall (Credits: © anja koehler | andereart.de)

allowed the number of LEDs in an application to be reduced therefore reducing costs, but also pointed out that the "Free Epi" era is over and therefore cost reduction in the future has to be carried by other components of the BOM. Mr. McClear emphasized that cheap LEDs could cause much higher costs in other system components, especially optics and thermal management, than high quality and high performance LEDs that can withstand higher temperatures. Finally, he suggested performing product selections based on L90 instead of L70 lifetime ratings that would help to prevent hidden costs of up to 20%.

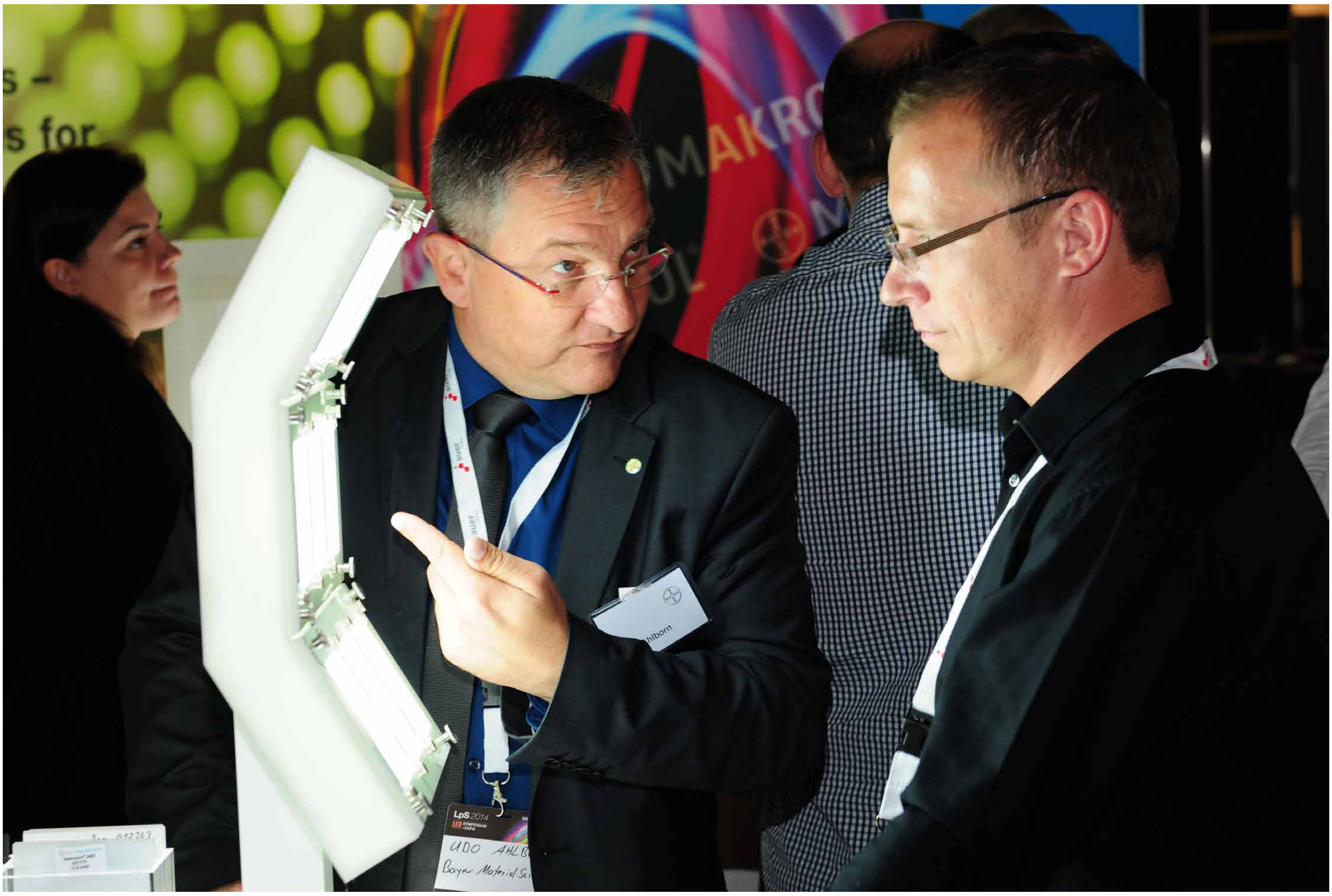
"Color Quality of High-End LED Products" was Prof. Tran Quoc Khanh's topic. He explained the V-Lambda function and claimed that perception differs individually. Then he showed how the human visual signal processing works. He also showed which parameters are taken into account today and which ones should be considered in future regulations. He indicated how and why it is important to add red phosphor to the green phosphor for high color rendering and that these red phosphors don't have high efficacy today. He defined criteria for high-end LED lighting systems and a 2700 K to 5000 K color tunable hybrid-LED luminaire with the inherent controls algorithm for mixing 6 LEDs (warm-white, red, deep red, green, royal blue and blue) for a high CRI.

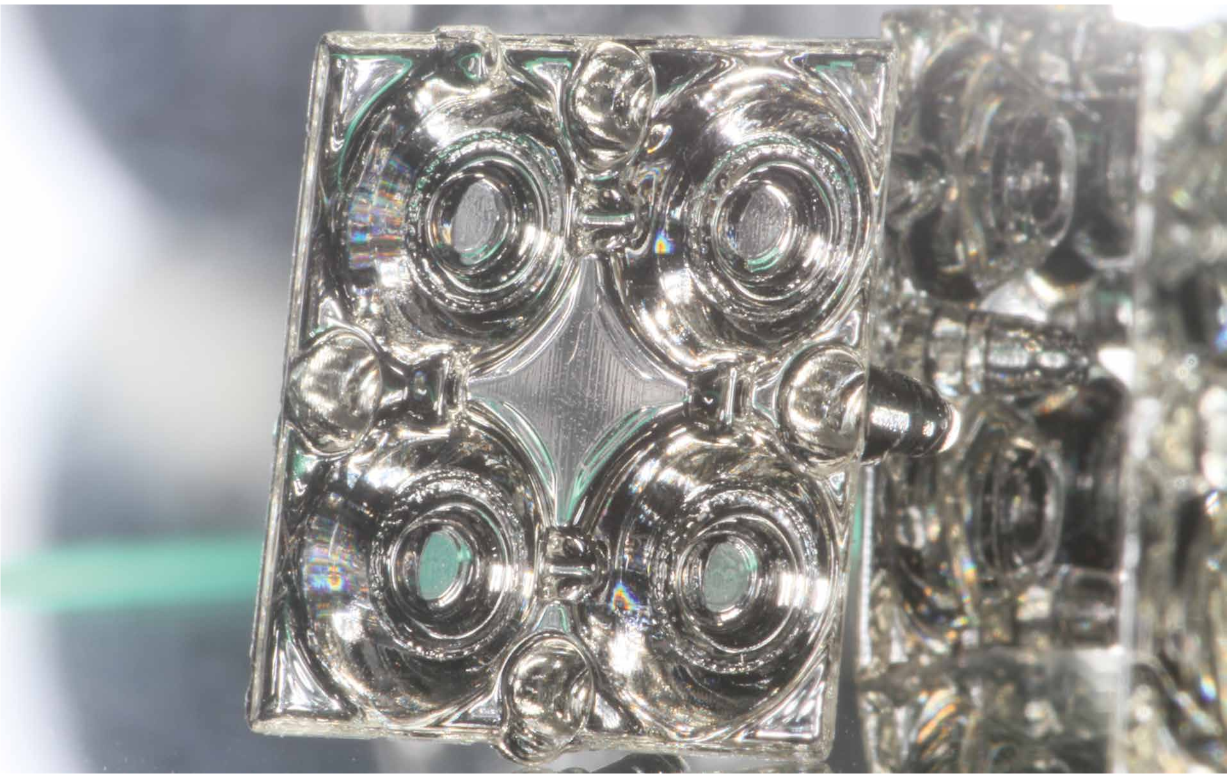
Top Scientific Lectures and Product Launches

The topics of the keynote speeches were ever-present during the sessions, in specialist discussions, the Tech Panels, and on the exhibition floor. The messages of the keynotes were underlined by the product launches, the lecture highlights and the scientific papers. The following selected examples demonstrate this well.

Prof. Reine Karlsson's emphatic appeal to design and provide the right light, useful light, and to develop innovative future concepts, "Intelligent Lighting for People", was the topic of many lectures. It was especially apparent in the lectures about smart and human centric lighting. Walter Werner presented a paper on "Components, Controls and Networking Environment Challenges of Human Centric Lighting", which further highlighted the various aspects of this field. In particular, he introduced the control challenges and drew attention to future "meta-parameter" control which could allow a user to parameterize systems in his own words thus allowing users to influence the lighting in more result-oriented, human terms. Nicola Trivellin explained the melatonin process as well as the color rendering and the perception of whiteness. He demonstrated his interpretation of human centric lighting by proposing that a tunable white LED system is able to achieve high CRI (above 90) in a large CCT range (2800 – 5500 K). This could be seen live at the LightCube booth in the exhibition area. Tanzim Baig from the Holst Center talked about another technology for providing "meaningful light"; OLEDs. In his lecture "Flexible OLEDs for Lighting Applications", he discussed the technical issues that have to be solved to allow cost-effective mass production, in particular using the currently most promising roll-to-roll (R2R) process. In an expanded interpretation of the word "intelligent" in intelligent lighting, Prof. Dr. Eberhard Waffenschmidt also dealt with this topic. The professor from the Cologne University of Applied Science gave insights into the future concept of DC grids and the status of LED lighting applications in DC grids, especially with a high voltage supply at 380 VDC. In a similar sense, several products on the exhibition floor could be classified as either intelligent, or smart, and certainly useful solutions! ELT launched several LED drivers that are characterized by a universal, wide input voltage range, extremely low output current ripple and THD without compromising

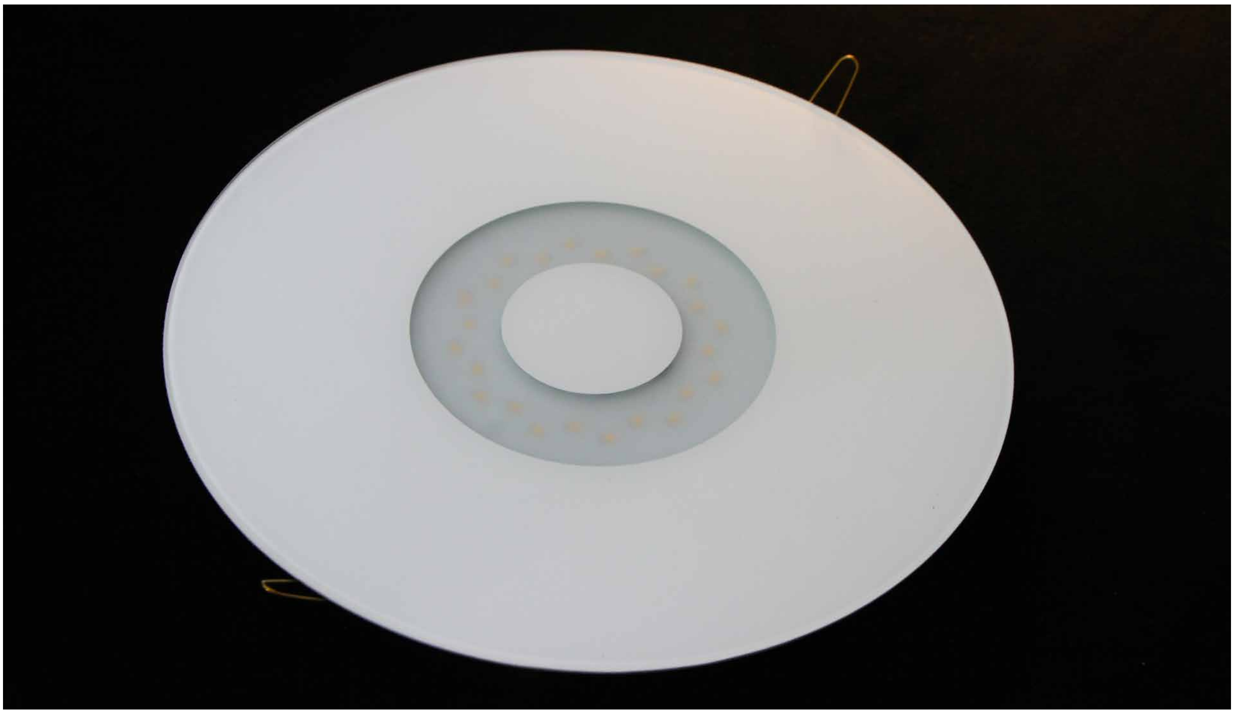
Figures 6-8: **The session breaks were used to continue discussions with the experts in the exhibition hall**





Figures 9-16:
The eight official product launches at LpS 2014 were: Everfine's high accuracy laboratory and hand-held spectro-radiometers, Auer Lighting's borosilicate glass based lightguides, a rack-mount spectroradiometer with software that allows for easy integration of other measurement equipment from GL Optics, an improved process and material for 3D printed optics for a height of up to 20 mm presented by LUXeXceL...

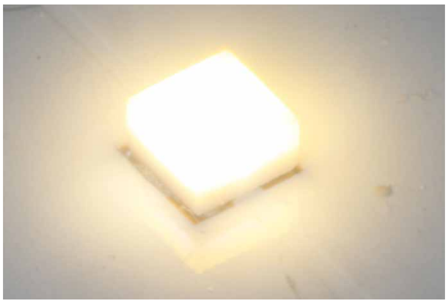
... Data Link's driverless luminaire manufactured almost entirely using an automated robotic line process, a very fast spectroradiometer from Gigahertz that is not only designed for binning, a wide input voltage range of LED drivers from ELT, and a ceramic coated MC-PCB with integrated heat sink and very low thermal resistance launched by BQ Ceramics



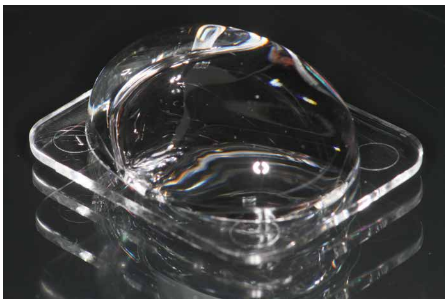
Figures 17 & 18: **The highly anticipated lectures given by top-notch speakers were extremely well frequented**

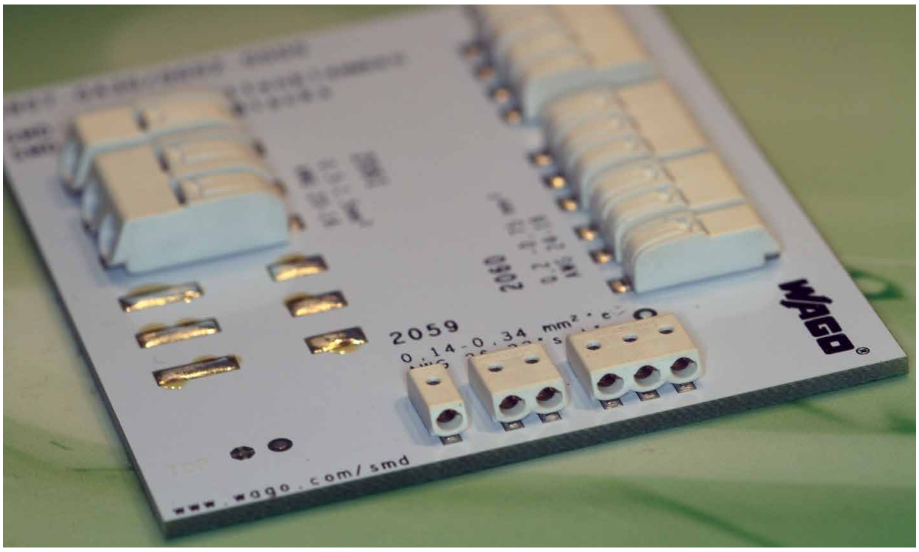
efficiency and power factor. The intelligence of Data Link's new Flush Mount Ceiling Lamp designed with AC LED technology and their patented "planar technology" lies in the fact that this approach allows assembling by an automatic robotic line with minimum human involvement. LUXeXcel's aim to provide smart and intelligent lighting is based on the flexibility of their optics manufacturing approach. Their method is also cost effective for low to medium numbers and therefore variations of an optic to perfectly match the light distribution to the different requirements within a project at reasonable costs are possible. This year they introduced the next generation 3D printing process for optics and a new clear material that clearly expands their prospects.
This means that not only is the manufacturing of high quality optics up to 20mm in height possible, but there is also improved precision that provides smoother surface structures. By this means the production of small and mid-size optics using the 3D printing process is becoming competitive with injection molding.

Mark McClear's statements regarding high quality LEDs, the trend to reduce the number of LEDs in many applications and to high power LEDs with all its technical consequences was accommodated by the product launch of the LpS 2014 Lanyard Sponsor, Auer Lighting. Their new light guides, made of borosilicate glass, using cost-competitive injection molding technology, can better resist heat than their plastic counterparts and they offer low thermal expansion and zero water absorption that allows for precise light guidance along difficult environmental conditions.
The increased number of silicone-based optics in the exhibition area took this trend into account as well as the innovative and cost-effective innovation that BQ Ceramics showed to the public for the first time.
Their Polar Light Technology is the first ceramic-coated metal core PCB that can directly integrate a heat sink. It offers superior thermal conductivity at a reasonable cost. Cree's latest developments, the XLamp® MH-B LED was also presented for the first time at a European exhibition. The same is true of Sharp's Intermo LED module that was displayed at the Silica booth (their distributor). The underlying message came across in the submissions of several papers like the one from Martin Pfeiler-Deutschmann who spoke about "Experimental Techniques and FEM Simulation for Evaluation of Thermo-Mechanical Stress in LED Devices" and Wolfgang Nemitz's presentation on "A Self-Compensation Approach for



Figures 19-24: Not only were the official product launches of great interest, but the latest products and information about developments from all of the other exhibitors were exceedingly intriguing. A few examples were Crytur's outstanding crystal phosphor, TSMC's Chip LED at the Holders booth, Gaggione's silicone lens, Cree's latest LEDs, WAGO's miniature power terminal block series and newcomer KDG-Opticomp's high precision PMMA lens





Voices from LpS 2014

"In my opinion the LpS is one of the most important global LED events. Actually, it is one of the only places where you really get all of the aspects related to the LED", said Heinz Seyringer, Head of Research Collaborations at Zumtobel and board of stakeholders at Photonics 21.

Prof. Mehmet Arik from the Ozyegin University said, "I was impressed with the quality of keynotes and the technical presentations, which were well chosen. I believe this event will grow even bigger over time".

"I attended different workshops from optical design to LED future technologies and there were a lot of new thoughts for future developments, especially for our company", said Mr. Peter Tanler from the Bartenbach Research Institute.

Mr. Tanzim N. Baig, Key Technology Developments at Holst Centre, stated, "It is a good platform to really get the ideas in and to understand each other's perspectives. I'm quite glad I'm here."

"The LpS is a really important venue for not only local and European companies and suppliers but also for international ones. A show like the LpS is important for us to meet our customers and they are all here - so we are here. We've done a lot of business so we are very pleased with the venue and organization. We would really like to come back again", stated Mark McClear, Vice President Global Sales at Cree.

"We visited this conference for the third time this year and we saw that the market and industry leaders are here. This is why we thought the LpS is the best opportunity to launch a product", stated Anke Kruse from Auer Lighting.

"It's the first time I'm here and I'm really glad to see that what I was told before is what I hear back from the exhibitors and visitors here at the event: the high quality of the audience, the high quality of the conference and the opportunity to have really intimate discussions to understand the manufacturing issues and the new technology trends." Carlos Lee, EPIC. ■

Maintaining the Chromaticity Coordinates of Phosphor Converted LEDs upon Temperature Variations". The latter addresses the challenge of white light quality requirements like keeping the chromaticity coordinates of a single LED light source constant during operation and lifetime. The paper proposes the use of a multilayer set-up, in which an additional silicone layer is used for encapsulation that can be applied to compensate different values of phosphor luminescence intensity reduction. Once the temperature dependency of the luminescence intensity reduction of the phosphor is known, an appropriate combination of silicones with different thermo-optic coefficients or different designs can be chosen to counterbalance a color shift. Another scientific paper that should be mentioned dealt with the drawbacks of red phosphors to being hygroscopic and having the potential to be degraded by atmospheric moisture and high temperatures. In her lecture on "Al_2O_3 coated Europium-Activated Aluminum Silicon Nitride for use in COB-Technology in LED", Nika Mahne from the Graz University of Technology demonstrated an approach to improve stability using an Al_2O_3 coating.

The hot topic from Prof. Khanh from the Technical University Darmstadt on color quality affects several technology fields; one is certainly measurement and testing. Following the industry's demands for light measurement tools with improved speed, accuracy and interconnectivity three of the worldwide leading companies launched products that satisfy these requirements exactly. Everfine presented their new high accuracy array spectro-radiometer, the HAAS-3000 for the first time in Europe. It incorporates two innovative approaches to improve stray light rejection and linearity of the measurement system. It can measure a flashlight of less than 1µs with 0.3% linearity, 0.01 mcd sensitivity, and an x/y-accuracy of 0.0015. Stray light is suppressed to a level below 5.0×10^{-5}. They also released the hand-held SPIC-2000 spectral irradiance colorimeter that offers the highest accuracy in its class, worldwide, and a minimum measureable illuminance of 0.01 lx. Everfine's founder, Prof. Jiangen Pan presented measurement technologies and accuracy in his lecture entitled, "High Accuracy Array Spectro-Radiometer Techniques for Measurement of LEDs". Two European light measurement specialists also showed their new products to the public for the first time. With their new spectro-radiometer, Gigahertz Optics not only focuses on binning, for which the new BTS2048-VL is perfectly suitable, it also offers measurement times between 2 µs and 4 s and 7 ms including the complete data record via LAN. The precise synchronization of the measurement device with the system process may also be a good argument for industrial application. With the other well-balanced technical specifications it might also find its place in some research laboratory. GL Optics recognized a demand for rack-mount light measurement tools that can integrate other measurement equipment in their software easily to perform efficiency measurement. To satisfy this demand they introduced the GL Spectis 6.0 at the LpS. While the technical parameters are not very much different from their existing Spectis spectro-radiometer series, they improved the value through the new software that allows an easy implementation of other measurement equipment – for instance power meters – and power sources. Many lectures also dealt with Prof. Khanh's central topic of light quality in one way or the other. All the lectures on phosphors covered light quality issues and Dr. Kevin Smet, representing the Leuven University and CIE gave insights on the development progress and utilization of a new standard for color quality evaluation in his lecture titled, "The CRI2012 Color Fidelity Index and its Practical Application". The award winning paper, "New Binning Strategy for White LEDs to Improve the Color Quality of Interior Lighting" by Dr. Peter Bodrogi, Technical University Darmstadt perfectly complimented the keynote speech. The paper recognizes the deficiencies of the ANSI binning strategy that is based on the visually false magnification of MacAdam's ellipses. A new binning strategy is proposed to describe and easily communicate the magnitude of acceptable chromaticity differences. The new binning strategy assigns any instrumentally measured chromaticity difference a so-called semantic interpretation. The method can be applied to any chromaticity center (e.g. a desired target chromaticity of the LED light source like a certain cool white tone) and to any direction in the chromaticity diagram. Semantic interpretations are formulated in terms of natural language and represent a common basis of white LED binning communication between customers and manufacturers. The full paper can be read on page 48.

Interactive Workshops and Tech Panels

Two panel discussions were held on the third day. The format of the panel discussions was modified this year to encourage a more informal dialogue between the panelists and the audience. Audience members could join the panel at any stage and be a part of the ongoing discussion.

This "Interactive Day" was opened with the keynote from Prof. Mehmet Arik from the Ozyegin University on "Breakthrough Technologies and Strategies in SSL Developments - Thermal Managements of LEDs". In his compelling speech, he explained the synergy between SSL and advanced micro electronics, emphasized the importance of a cross functional, interdisciplinary research and approach, and showed that even with improved LEDs and despite future improvements, thermal management will still be an issue. He compared the currently available cooling methods and concluded that - while microfluidics technologies such as synthetic jets may help to reduce heat sink size and provide adequate cooling - novel cooling technologies need to be invented.

The first panel discussion entitled "International Year of Light 2015 – Strategies and Technologies" brought together experts from industry, universities and research organizations. The panelists, Prof. Reine Karlsson (Director Inside Light, Lund University), Mr. Carlos Lee (Director General, EPIC), Mr. Dietmar Zembrot (President

Fact Sheet on "Best Papers" at LpS 2014

According to the conditions listed for the Scientific Award, the top 6 papers will be published in the LED professional Reviews. The publication issue is not related to the rank, but rather to how it relates to the "Magazine Spotlight".

LpR 46 | Nov/Dec 2014:
Winner Article: New Binning Strategy for White LEDs to Improve the Color Quality of Interior Lighting
by Dr. Peter Bodrogi,
Technical University Darmstadt
After having recognized the deficiencies of the ANSI binning strategy which is based on the visually false magnification of MacAdam's ellipses, a new binning strategy based on a so-called semantic interpretation is proposed to describe and easily communicate the magnitude of acceptable chromaticity differences. The new binning strategy resulted from a series of visual experiments on the semantic interpretation of instrumentally measured color differences. Semantic interpretations are formulated in terms of natural language and represent a common basis of white LED binning communication between customers and manufacturers.

LpR 47 | Jan/Feb 2015:
Citation Article: Field Study of LED Office Lighting for Improved Well-Being and Performance
by Katrin Möller,
Competence Center Light
The effects of lighting on human well-being and performance of LED and fluorescent lamps have been investigated in a comparative laboratory study. Two different lighting scenarios (static and dynamic lighting) were implemented and evaluated for both light sources. The results show that the LED lighting was rated more interesting, colorful, comfortable, warm, inviting and beautiful than fluorescent lighting (evaluation, p=0.004) as well as more casual, private and pleasant than fluorescent lighting (p=0.058). No significant differences were found between LED lighting and fluorescent lighting concerning well-being, performance and concentration. Some significant effects were seen during the night following the test day.

LpR 48 | Mar/Apr 2015:
Citation Article: Direct Current (DC) Supply Grids for LED-Lighting
by Prof. Dr. Eberhard Waffenschmidt,
Cologne University of Applied Science
Most electrical devices operate on direct current (DC) internally, but are supplied by alternating current (AC). A DC grid apparently seems to have advantages. Solutions of DC operated professional buildings like offices or supermarkets and homes with a special focus on high voltage supply at 380 VDC were researched. The component effort for solutions with AC and DC current supply was compared and showed that LED-lamps can benefit from a DC supply because lamp drivers can be reduced to a few reliable components. The investigations also showed that a major advantage of a DC supply appears if a micro-grid including decentralized energy generation and storage is considered.

LpR 49 | May/June 2015:
Citation Article: Self-Compensation Approach to Reduce Color Shift of Phosphor Converted LEDs upon Temperature Variations
by DI Wolfgang Nemitz,
Joanneum Research
Keep the chromaticity coordinates of a single white LED light source constant during operation and its lifetime is still a huge challenge. A sophisticated composition of the materials used in the color conversion element (CCE), which typically consists of the phosphor particles embedded in a silicone matrix could improve the color temperature constancy under different operational conditions. The article shows that an appropriate combination of two layers of silicones with different thermo-optic coefficients (and/or filling them with different concentrations of scattering particles) can be applied to counterbalance several different levels of temperature induced color variations.

LpR 50 | July/Aug 2015:
Citation Article: Flexible OLED Technologies for Lighting Applications
by Tanzim Baig,
Holst Center
Roll-to-roll (R2R) compatible technologies with high yield are recognized to be key for affordable and competitive OLED lighting product manufacturing. Devices on plastic and metal foil substrates with solution processed multilayers deposited using our R2R line, large area transparent electrodes including printed metal grids, techniques for light extraction in flexible devices and state-of-the-art thin film flexible water barrier performance (black spot free flexible OLEDs after more than 2000 hours in 60°C/90%RH accelerated lifetime conditions) is demonstrated.

LpR 51 | Sept/Oct 2015:
Citation Article: Al2O3 Coated Europium-Activated Phosphor for use in COB Technology
by Nika Mahne,
Graz University of Technology
Eu2+ activated red nitride phosphors like CaAlSiN3:Eu2+ have drawn much interest, but they are hygroscopic and have the potential to be degraded by atmospheric moisture and high temperatures under operation. In order to improve its stability against moisture and oxidation for use in chip on board technology, a $CaAlSiN_3:Eu^{2+}$ phosphor was coated with Al_2O_3. The Al_2O_3 coating was obtained via a Brønsted precipitation reaction based on a solution-coating process from a mixture of aluminum halide with a base, after annealing at a temperature of 400°C, to obtain an Al_2O_3 coating. In addition to XRD, ATR-IR and SEM (SE, BSE and EDX), luminescent properties were determined. ■

Figure 25:
Prof. Mehmet Arik's inspiring keynote speech opened the interactive activities on Day 3

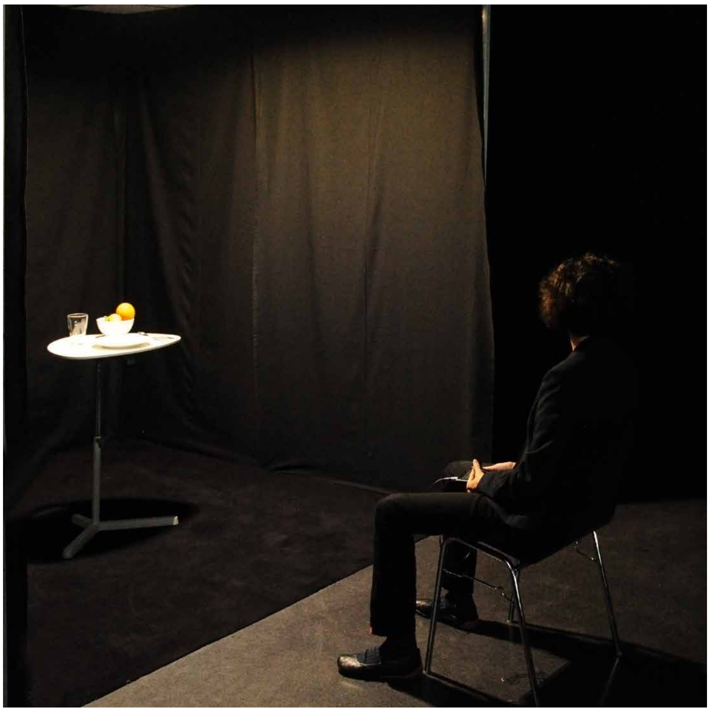
of LightingEurope) and Mr. Colin Faulkner (Board of Directors, TCLA) discussed the opportunities and challenges for future lighting, the impact of new innovations such as Human Centric Lighting as well as European strategies and feedback. The key outcomes of this discussion were that while new innovations can accelerate Europe's competiveness, the benefits of lighting, as a whole, needs to be communicated more effectively to the general public. The International Year of Light 2015 could go a long way in creating this awareness. Further, feedback from the experts indicated that the perception of "lighting" should and will change in the future as technologies become more integrated and user oriented.

The second technical panel discussion was on "Design and Engineering for Future LED Lighting Systems - The Cornerstones of LED Lighting System Developments". Dr. Martin Zachau (Head of Research, OSRAM), Dr. Kevin Smet (postdoctoral fellow Light and Lighting Laboratory, Leuven University), Dr. Mehmet Arik (Professor, Ozyegin University), Dr. Norman Bardsley (President, Bardsley Consulting) and Mr. Arno Grabher-Meyer (Editor in Chief, LED professional) provided interesting insights into the main cornerstones of LED lighting systems; innovative technologies, development and maintenance and engineering processes with particular emphasis on new approaches/innovations in smart lighting, main limiting factors and potential innovations in engineering processes for the future. Dr. Nicola Trivellin (co-founder LightCube Srl) was invited as a key expert to introduce and discuss reliability issues in SSL. Following up from the previous discussion, the experts pointed out that SSL technologies have indeed come a long way and current research is well geared to meeting specific challenges. There was a common consensus that the three main driving forces for future SSL technologies would be cost, reliability and new applications and that rather than trying to replicate conventional uses, the future could concentrate on new and improved applications for this technology.

Five workshops were held in parallel this year covering a wide range of topics from optics design to optics 3D printing, to smart lighting electronics concepts, to wireless lighting controls, and visual perception. Dominic Harris, founder and director of Cinmod Studio and winner of "Best Luminaire" at the Lighting Design Awards 2014 presented his ideas on the fusion of Architecture and Lighting Design and how 3D printing technology based optical designs helped to enrich their projects and create new and unique features as part of LUXeXceL's workshop on the next generation of 3-D printed optics. The workshop was held in two sessions; one technology session and one application session. It gave an impressive demonstration of how, with the latest technical progress in this field, new opportunities for lighting designers and luminaire manufacturers originated. The participants were encouraged to discuss the presented ideas and opportunities and to bring in their own creative ideas for the 3D printing technology.

Dialog Semiconductors held a workshop on "LED Driver Concepts for Smart Lighting". This provided an introduction to DLT, Bluetooth and Toggle switch based dimming with Demonstrations. This was followed by a breakout session with three groups working on 3 key questions in wireless lighting: Will end users control their homes with smartphones? Is connectivity to the Internet important for LED lamps? What is the relevance of local (room based) control vs. centralized control? An experiment was conducted to create a visible light modulation at low dim levels to experience the high sensitivity of the human eye to small current modulations.

Figures 26-29: Interactive activities included exploring the effects of spectral quality on visual perception, participating in two panel discussions or looking for answers to three key questions on wireless lighting



As another highlight, Markus Canazei and Wilfried Pohl from Bartenbach Research and Development demonstrated different lighting quality criteria by active involvement of the participants. Looking into small light boxes the participants could experience spectral quality issues like color fidelity and preference, whiteness, etc., and the difference between a 2° and a 10° observer. In a real scaled room mock-up, different illumination concepts were demonstrated and the participants calculated UGR glare values by measuring horizontal and vertical illuminance and luminance values. They could experience the effects on room appearance, face and subject cognition, shadiness, contrast vision, etc. themselves. The audience response was very positive and some said that the workshop demonstrated lighting effects like they had never seen before!

Summary and Outlook

The LpS 2014 closed its doors on October 2nd, having once again provided three exciting days of high quality, provoking lectures that led to inspiring conversations and discussions not only during the lectures but also on the exhibition floor and even on the sold out Get Together event aboard the MS Vorarlberg. The predictions made in 2013 have proven to be true and are expected to hold in the future. While efficacy is still a topic for the public, specialists agree that quality improvements and optimizations towards more useful, user-friendly, and even more reliable and cost-effective LED illumination and LED products will be the major topics during the next few years. The designations "smart lighting" or "human centric lighting", don't really describe the requirements and future expectations in LED lighting properly. Prof. Reine Karlsson's concept, "Intelligent Lighting for People" adds one substantial factor to the equation: "for people". That means the industry needs to listen to the requirements of the people. They cannot randomly define what is smart and what is human-centric, because the end user and the industry specialist may perceive them differently. While there may be room for improvement, most products at the exhibition, as well as the lectures and workshops clearly demonstrated that this has been recognized by the industry leaders. The slogan "…for people" might become even more important in 2015 and if it does, the LpS 2015 will be there to accommodate it from September 22nd to 24th 2015. ■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New Binning Strategy for White LEDs to Improve the Color Quality of Interior Lighting

After having recognized the deficiencies of the ANSI binning strategy, which is based on the visually false magnification of MacAdam's ellipses, Dr. Peter Bodrogi and Prof. Tran Quoc Khanh from the Technical University Darmstadt propose a new binning strategy based on a so-called semantic interpretation to describe and easily communicate the magnitude of acceptable chromaticity differences.

The LED light sources of the luminaires to be used for interior lighting need an efficient i.e. visually relevant chromaticity binning strategy in order to achieve a certain target chromaticity and also to maintain good color homogeneity on white surfaces and on colored objects. For such a binning strategy, the magnitude of visually acceptable chromaticity differences shall be known. After having recognized the deficiencies of the ANSI binning strategy that is based on the visually false magnification of MacAdam's ellipses, the authors of this paper suggest a new binning strategy to describe and easily communicate the magnitude of acceptable chromaticity differences. The new binning strategy assigns any instrumentally measured chromaticity difference expressed by a modern color difference metric (CAM02-UCS), a so-called semantic interpretation around any chromaticity center e.g. a target white point for the white LED light source. "Semantic interpretation" means that every chromaticity difference is interpreted by one of the following categories: "very good", "good", "moderate", "low" or "bad" while "very good" means a "very good" agreement of perceived chromaticity between a target chromaticity and the actual chromaticity. The new binning strategy resulted from a series of visual experiments on the semantic interpretation of instrumentally measured color differences. Semantic interpretations are formulated in terms of natural language and represent a common basis of white LED binning communication between customers and manufacturers.

Introduction

Before the construction of a LED luminaire to be used for interior lighting, to achieve a certain target chromaticity and to maintain the color homogeneity of the luminaire, an efficient chromaticity binning strategy of the LED light sources is important. Chromaticity binning means the sorting of the LED light sources into chromaticity categories (so-called bins) after production. The question is the magnitude of visually acceptable chromaticity differences within a bin (i.e. the set of actual LED light sources to be installed in the luminaire) and also, between any LED light source inside the bin and a desirable target chromaticity, e.g. a visually preferred white tone.

The American National Standard ANSI ANSLG C78.377-2011 specifies white light chromaticities in terms of a set of binning ranges in the CIE 1931 x, y chromaticity diagram or in the CIE 1976 u', v' chromaticity diagram. ANSI binning categories are based on MacAdam's ellipses that describe just noticeable (i.e. very small) color differences. From visual studies of literature it is obvious that a simple magnification of these ellipses without changing their shape and orientation cannot describe above-threshold (small to medium) color differences that are relevant for the practice of chromaticity binning. In this work, an advanced, visually relevant LED chromaticity binning strategy is presented in order to communicate the magnitude of chromaticity differences between the LED light source manufacturer and the producer of the interior lighting product.

New Binning Strategy for White LEDs

The new binning strategy assigns any instrumentally measured chromaticity difference a so-called semantic interpretation. The method can be applied to any chromaticity center (e.g. a desired target chromaticity of the LED light source like a certain cool white tone) and to any direction in the chromaticity diagram. The concept of semantic interpretation means that, depending on the chromaticity center and the direction in the chromaticity diagram, every chromaticity difference is interpreted by one of the following semantic categories: “very good”, “good”, “moderate”, “low” or “bad”, or by the aid of intermediate categories like “moderate-good”. E.g. “very good” means a very good agreement of perceived chromaticity between the center in the chromaticity diagram (i.e. the target chromaticity to be achieved by the LED light source) and the actual chromaticity of the LED.

The new binning strategy is based on the result of a series of visual experiments on the semantic interpretation of instrumentally measured color differences [1]. These color differences were expressed in terms of the visually uniform so-called CAM02-UCS color difference metric (ΔE’) [2]. Observers of this study [1] were asked to follow a very critical and demanding attitude in the context of a color inspection task and interpret color differences between numerous pairs of colors by the aid of the above semantic categories. As mentioned above, every ΔE’ value was assigned a semantic interpretation in the previous study [1]. The agreement between the two color stimuli was assigned the category “very good” if ΔE’ was equal 0.00, “good-very good” for ΔE’=1.05; “good” for 2.07; etc.

The CAM02-UCS color difference metric is more reliable than the using of multiples of MacAdam’s ellipses (e.g. 1-step, 2-step, 7-step MacAdam ellipses). The reason is that MacAdam’s experiments were based on chromatic adaptation to a single chromaticity (daylight), on a single observer and only on the measurement of just noticeable color differences. The upscaling of these just noticeable color differences (e.g. 7-step MacAdam) tends to cause unpredictable visual errors. The CAM02-UCS metric, however, was designed to predict the whole range of magnitude of color differences relevant to white LED binning.

The method of the new binning strategy transforms every value of the CAM02-UCS color difference metric (ΔE’) into the CIE 1931 x, y chromaticity diagram around any chromaticity center in any direction. Then, the semantic contours of “very good”, “good”, “moderate”, “low” or “bad” agreement with the chromaticity of the color center are computed in every direction around the color center. Within the areas between neighboring semantic contours in the CIE 1931 x, y chromaticity diagram, the nearest category to the considered chromaticity point shall be applied.

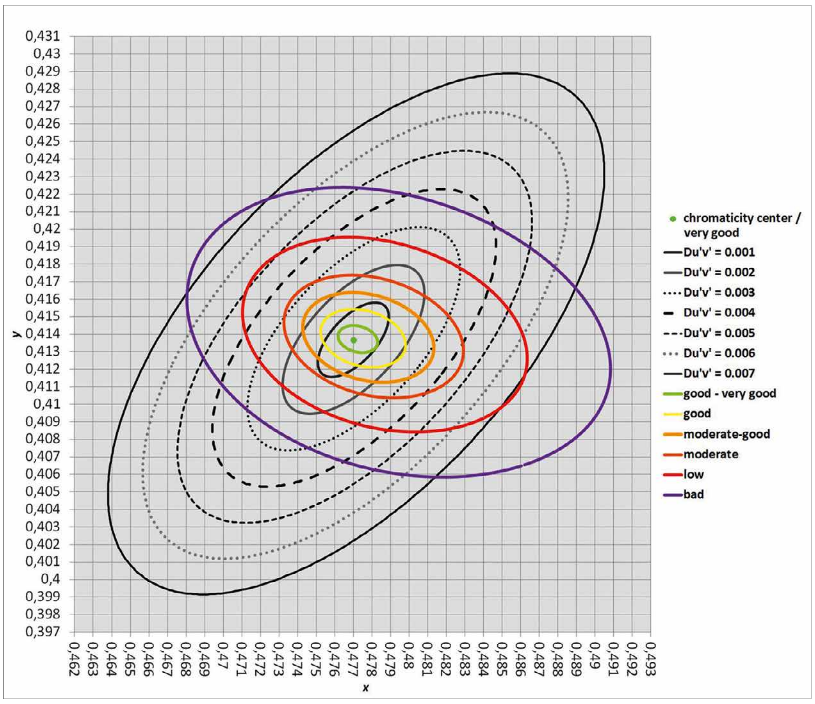

Figure 1: Semantic contours for chromaticity differences from the chromaticity center in the CIE x,y chromaticity diagram for a warm white chromaticity center, the Planckian radiator at 2500 K; x=0.4770; y=0.4137 (light green dot). Going off the center in any direction, contours indicate “good-very good” (green contour), “good” (yellow contour), “moderate-good” (orange contour), “low” (red contour) and “bad” (lilac contour) perceived color agreement with the center. Contours of constant chromaticity differences (Δu’v’=0.001 - Δu’v’=0.007 i.e. approximations of MacAdam ellipses) measured from the chromaticity center are also shown

Result and Discussion

Semantic contours of the new binning strategy are shown in the CIE 1931 x, y chromaticity diagram of Figure 1 for a warm white chromaticity center, the Planckian radiator at 2500 K, x=0.4770; y=0.4137. Semantic contours are compared with contours of constant chromaticity differences (Δu’v’=0.001 - Δu’v’=0.007) in the u’-v’ diagram measured from the chromaticity center. These constant Δu’v’ contours approximate 1-step to 7-step MacAdam ellipses (i.e. MacAdam ellipses magnified 1x to 7x).

As can be seen from Figure 1, the orientation of the constant Δu’v’=0.001 - Δu’v’=0.007 contours and the orientation of the semantic contours is different. At this chromaticity center (x=0.4770; y=0.4137), the different shades of white (i.e. the different white points) along the Δu’v’=0.001 ellipse may correspond to “good-very good”, “good” or “moderate-good” color agreement with the center (the light green point i.e. the target white point), depending on direction, see the intersection points of the Δu’v’=0.001 ellipse (black curve) with the green, yellow and orange semantic contours in figure 1.

Semantic contours of the new binning strategy are shown in the CIE 1931 x, y chromaticity diagram of Figure 2 for a phase of daylight at 6000 K, x= 0.3216; y=0.3377. Semantic contours are compared with contours of constant chromaticity differences (Δu’v’=0.001 - Δu’v’=0.007) in the u’-v’ diagram measured from the chromaticity center.

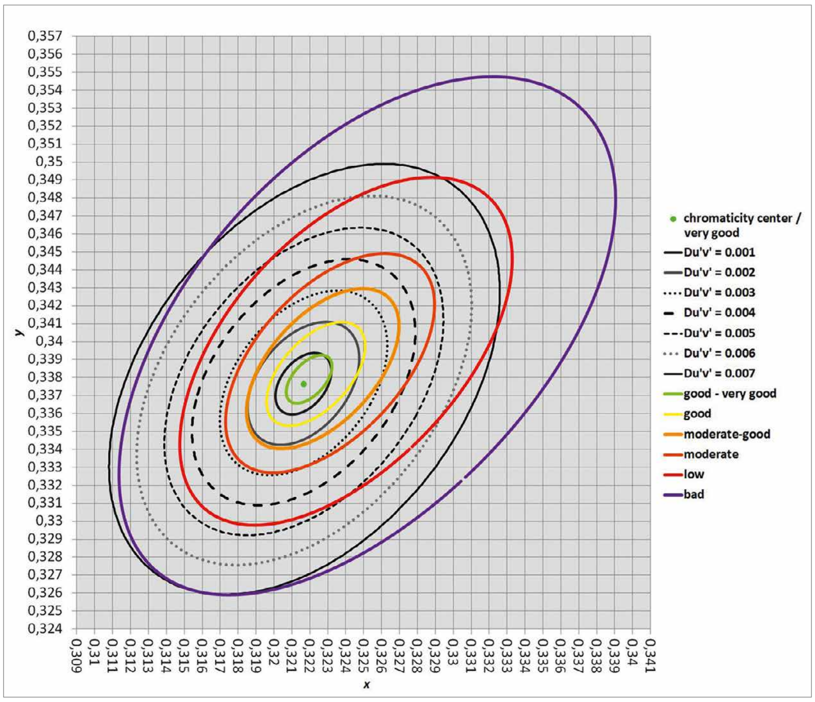

Figure 2: Semantic contours for chromaticity differences from the chromaticity center in the CIE x,y chromaticity diagram for a phase of daylight at 6000 K, x= 0.3216; y=0.3377 (light green dot). For explanations, see the caption of Figure 1

As can be seen from Figure 2, the orientation of the Δu'v'=0.001 - Δu'v'=0.007 contours and the orientation of the semantic contours is similar. At this chromaticity center (x=0.3216; y=0.3377), the different white tones along the Δu'v'=0.001 ellipse (black) correspond approximately to "good-very good" agreement with the center (the green curve exhibits a similar course as the black ellipse). The different white tones along the Δu'v'=0.002 ellipse may correspond to "good" or "moderate-good" color agreement with the center (the light green point i.e. the target white point), depending on direction, see the intersection points of the Δu'v'=0.002 ellipse (grey) with the yellow and orange semantic contours in figure 2.

Conclusions

In this paper, the deficiencies of the ANSI binning strategy resulting from the use and magnification of MacAdam ellipses were pointed out. The proposed new binning strategy for white LEDs uses an updated color space (CAM02-UCS) and easy-to-understand binning categories, e.g. "very good". Extending the method to non-white chromaticity centers, the color homogeneity of colored objects can also be characterized. Advantages of the new binning strategy compared to ANSI binning include that the semantic contours corresponding to "good-very good", "good", etc. visual agreement of the considered white LED chromaticity with the chromaticity of the center (target white chromaticity) carry a straightforward meaning because these categories are formulated in terms of everyday language (e.g. "good") instead of using a multiple of the size of an (approximated) MacAdam ellipse. Semantic categories of color similarity communicate the magnitude of chromaticity differences between the LED light source manufacturer and the producer of the interior lighting product effectively. ■

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Cost Issues in the SSL Production Chain - From Substrate to the Luminaire

Estimates of the global capacity for the manufacture of LED lights and output at each stage of production are widely different. One important factor concerns the production of good dies from the substrate wafers – what fraction of the input sapphire or SiC is discarded? How much light is produced from each mm^2 of good die and how much light is needed to meet global demands? J Norman Bardsley from Bardsley Consulting made an analysis of the complete value chain, extending to R & D costs. Profit margins and sales volumes is used to highlight issues of price premiums over traditional technologies, supply-demand imbalance and regional differences between China, Europe and the USA.

Manufacturing costs and production capacity are two topics that receive little public discussion amongst the LED community. However, efficient manufacturing is critical to meeting the stringent cost targets of the lighting market and misunderstanding of the supply-demand balance often leads to serious damage to company profitability and growth. Back in 2009 it became clear that the market for LEDs could grow substantially, first in display backlights and then in general lighting. During 2010 and 2011, enthusiasm gave rise to over-investment in MOCVD tools and in the production of sapphire substrates. The resulting over-supply led to a collapse in the market for sapphire – the price of a polished 4" wafer fell from US$130 at the beginning of 2011 to $50 in mid-2012 and $30 in 2013. Sales of MOCVD tools fell by 70% from 2011 to 2012 and have yet to show substantial recovery. Fortunately, the two leading suppliers, Aixtron and Veeco, were able to survive and have continued to invest in R&D.

With the steady growth in demand for LEDs, many LED manufacturers are now operating near full capacity. However, the news that Apple intended to use sapphire substrates in smart phones once again led to a flurry of investment in new furnaces, with plans to commit over RMB20 billion announced by companies in China. Other sectors of the industry have been more cautious. One of the major aims of this article is to discuss whether such caution is justified.

With respect to price, it should be emphasized that most of the expenditure incurred in lighting is in the cost of the electricity, rather than the purchase and lamps and luminaires. This was clearly documented in the report "Light's Labour's Lost" [1], published by the IEA in 2006 and based upon a thorough study of the global lighting industry. At US$ 234 million, the annual cost of electricity accounted for two-thirds of the total cost of lighting service ($356 billion). For almost all applications, the additional cost of LEDs over traditional light sources can be recovered within 5 years. Even in domestic applications with incandescent or halogen lights that are used for only 2 hours per day, residents of areas with electricity rates in excess of $0.25 (or €0.20) per kilowatt hour can recover the cost of a general service LED lamp (GSL) in less than 2 years. How many other investments offer guaranteed annual returns of over 50%? Surely it is time for a media blitz on the economic advantages of solid state lighting!

Cost Structure for LED Dies

Fabrication costs vary significantly between manufacturers. The following analysis is meant only to give guidelines and is based upon public information from Aixtron and Veeco, along with the baseline data in the LEDCOM model of the US Department of Energy [2] and information gathered by the International Solid State Alliance.

The manufacture of GaN LED chips can be divided into two stages, epitaxial growth of the GaN crystal and semiconductor processing of the wafer to form the desired device structure with singulation to separate the individual die. Epitaxy requires the highest capital commitment, but both Aixtron and Veeco have made major advances in reducing the cost of ownership (CoO) of their tools. The CoO has been reduced by a factor of three since 2010 and the goal is for a further reduction of 30-40% over the next three years. Veeco estimates that capital depreciation now accounts for only 20% of the cost of the GaN wafer.

The massive investment in the production of sapphire ingots and wafers has led to the availability of unpolished 4" wafers at prices around $30. The premium for a 4" wafer over four 2" wafers has almost completely disappeared and use of the smaller size is no longer economic. However, there is still a substantial premium for larger wafers, which may not be justified by increased productivity. To facilitate light extraction, most manufacturers used patterned wafers which are priced in the range of $40-55 at 4" sizes. Reagents and other consumables add about $25, depreciation around $25, with a further $15 for utilities and other overheads. Through the use of highly automated equipment, labor costs can be less than 10%, so that it is still economic to make the chips in the US and Japan. Yields are high and the total cost of epitaxy is around $120.

The structure of the LED is formed using standard semiconductor processes. However, the wafers are relatively small and the die much larger than most microprocessor chips. The LEDCOM model suggests that the yield of 1mm2 chips consistent with the desired performance limits might be as low as 50%. Many of those that are functioning but off-spec in terms of brightness or color can still be used. However, the need for testing and binning each die can add substantial cost. The unyielded cost of this second stage is about $100, with major contributions coming from lithography, metal deposition, grinding and polishing, wafer dicing and wafer inspection. Labor costs are only high mainly in the inspection steps and may be enough to cause some manufacturers to perform the wafer processing in China or south-east Asia. SEMI estimates that the capital cost of the semiconductor equipment is about 35% of the MOCVD tools, so that depreciation contributes only around 10% of the wafer processing costs.

LED Packaging

Packaging costs include a relatively high labor content and so this stage is often performed in low-wage countries. Systematic cost reduction has been hampered by the wide variety of package designs and manufacturing techniques, but efforts are underway to develop approaches that are more amenable to automation. In the conventional approaches, materials typically account for 50% of costs with 25% in labor and 25% in depreciation and other overheads. The supporting structures and phosphor account for the major materials costs. Phosphor costs tend to be higher for low and mid-power packages in which the chips occupy a relatively low fraction of the total area, but the phosphor is deposited remotely over the whole package surface. In high-power chips the phosphor is often deposited directly on the chip. The baseline LEDCOM model estimates that phosphors account for 18% of the cost of a mid-power package but only 8% in high brightness LEDs.

The LEDCOM model suggests that phosphor addition and packaging account for about two-thirds of the cost of a white LED. In 2012, Yole Developpement [3] estimated that the combined contribution was only 55%, but cost reductions in epitaxy and wafer processing may have been more rapid than in packaging. Let us assume that the fraction is now 60%, so that the packaging adds around $330, bringing the unyielded cost of a processed 4" wafer to $550.

Assuming an edge exclusion zone of 3 mm, the usable area of a 100mm (4") wafer is 69 cm^2. With typical scribing channels of thickness 50 µm, the fraction of area lost in dicing is 18% for 0.5 mm x 0.5 mm die and 9% for 1 mm square die. The total area of processed chips is then 57 cm^2 for the smaller chips and 63 cm^2 for the larger ones. The unyielded chip cost is then in the range of $0.08-0.10 per mm^2.

LED Bulb Costs

Cost models for LED replacements for omnidirectional incandescent bulbs have been presented by Canaccord Genuity (CG) [4] and by Systems Plus Consulting through Yole Developpement (SPC/Y) [5]. CG examined the 800 lm bulbs introduced by Cree in September 2013. Ten 2.45 mm square packages are mounted on a ten-sided cylindrical stack inside the bulb. Each package contains eight die of 0.5 mm x 0.5 mm size, giving a total chip area of 20 mm^2. CG estimates the cost of the eight LEDs as $3.36 to $4.03, corresponding to $0.17 - $0.20 per mm^2. Assuming that Cree is able to obtain yields in wafer processing and packaging as 70-80%, this would provide room for corporate overheads, transfer costs and profit margins.

The CG analysis of the Cree bulb attributes 53% of the $7 manufacturing cost to the LEDs. Other component costs are 10% for PCBs, 20% for driver electronics, 9% for heat sink and 6.5% for the enclosure and packaging. Less than 2% is allocated to assembly. This demonstrates that the location of assembly operations should be determined by closeness to the customer or the supply of components rather than by labor costs. The SPC/Y analysis was for a 12 W 1000 lm LED bulb from Top Energy Saving System

Corp. of Taiwan (TESS). They estimated the cost of the LEDs as $2.50 out of a total bulb cost of $8. If both estimates are reliable, this comparison confirms that optimal design of LEDs can reduce the total cost of a lamp, even if the LEDs are more expensive.

LED Bulb Prices

The retail price of the TESS bulb was quoted as $19. This mark-up is typical and allows for the expenses of distribution and retail selling, with profit margins along the chain. The Cree bulb is sold exclusively through Home Depot, typically at a price of $9.99. Clearly the manufacturer and retailer have cooperated to streamline the supply chain and are accepting low profit margins to stimulate adoption of the new technology. An even more extreme example of this promotional pricing is seen in the supply of 7 W LED bulbs in high volume at 204 rupees ($3.40) by Philips in response to a tender by the Bureau of Energy Efficiency of India. As part of a collaboration with Energy Efficiency Services Limited and local utilities, the LED bulbs are being distributed to low-income consumers at prices well under $1. Such programs are designed to reduce the total cost of extending reliable electrical supplies to all citizens, especially to those who now have no connection to the grid.

LED Streetlights

Many municipal governments have been experiencing severe financial pressures and so are eager to adopt energy-saving measures wherever possible. The experience gained in Los Angeles and Seattle has shown that through very careful planning and product selection, the installation of LED streetlights can reduce life cycle costs in each of the main cost elements of energy, maintenance and equipment. Between 2009 and 2013, the price of LED lights fell by 60% while the efficacy more than doubled [6]. Through judicious purchasing agreements, high-quality street lights can now be purchased for around $15/klm plus a base charge of $80. This means that if the pole structure and power lines are in good condition, payback periods can be less than five years. Thus many municipalities will be able to choose between rapid economic relief through the installation of simple LED lights or longer term benefits from connected systems as part of Smart City strategies.

LED Production Capacity

About 2500 MOCVD reactors have been shipped since 2008, with almost half destined for China. Most of these have the capacity to process 14” wafers. Let us assume that the installed base includes 1500 tools at Tier 1 and Tier 2 manufacturers and 1000 at Tier 3 suppliers. Estimates of cycle time vary between 5 and 10 hours. Assuming that Tier 1 and Tier 2 suppliers carry out 3 runs a day, with ~15% downtime for regular maintenance, holidays and unscheduled stoppages, their combined annual capacity would be 1.4M runs, or 20M wafers. With a maximum of 2 runs a day, the contribution of Tier 3 manufacturers would be 9M wafers per year. The total of 29M is very close to the figure of 30M 4” wafers reported by SEMI. However, UBS Research and Yole Developpement estimate the capacity to be at or below 20M (80M 2” wafers).

Based on data from SEMI and Veeco, the average capacity utilization now appears to be around 80% for Tiers 1&2, but may be only 50% for Tier 3. Production would then be 21M 4” wafers. This is only slightly higher than the forecasts of wafer demand by UBS (19M) and Yole (16M). The die area that can be processed on these 21M wafers is around 125B mm^2. Assuming overall yields of 60% for Tier 1&2 and 50% for Tier 3, the area of good die produced would be 70B mm^2. This is just above the bullish forecast of Canaccord Genuity [7], which is based upon lower product yields.

Strategies Unlimited (SU) [8] forecast the revenues from packaged LEDs in 2014 to be $16B. This would suggest an average selling price of $0.22 per mm^2 of good die. The average value of each of the 21M processed wafers would then be about $750. SU attribute 40% of this revenue to lighting applications. Since die for lighting tend to be larger than those for other applications, let us assume that lighting is responsible for 30B mm^2 of finished die.

LED Lighting Markets

A glance at the products on the shelves of major retailers suggests that Chinese manufacturers are becoming dominant in the supply of LED lamps and luminaires. The Chinese Solid State Alliance (CSA) estimates that the value of LED lighting products made in China in 2013 was RMB112B ($18B) and anticipates growth to RMB170B in 2014 ($28B). Estimates by analysts from Europe and the US of total global revenues vary between $16B and $25B for 2013 and between $20B and $31B for 2014.

Table 1:
Chip and package requirements for LED lamps and luminaires in 2014

Output Class		Low	Mid	High	Super-High	Total
Output	kilolumen	0-1	1-3	3-10	>10	
Unit sales	million	800	350	90	10	1250
Average light per unit	kilolumen	0.4	1.8	5	20	1.3
Total light capacity	gigalumen	320	630	450	200	1600
Average efficacy	lumen/Watt	70	75	80	90	82
Total power	gigawatt	4.6	8.4	5.6	2.2	21
Power density on chip	W/mm^2	0.6	0.7	1	2	0.72
Required chip area	Billion mm^2	7.6	12	5.6	1.1	26
LED package price	US$/$mm^2$	0.2	0.25	0.3	0.3	0.25
Package revenues	US$ billion	1.5	3	1.7	0.3	6.5
Lamp selling price	US$/klm	10	15	20	20	16
Product revenues	US$ billion	3.2	9.5	9	4	26

Table 2:
Growth scenario for LED penetration of lighting

		2014	2015	2016	2017	2018	2019	2020	2021
Processing capacity	B mm²	70	77	85	93	102	113	124	136
Utilization	%	70	73	76	78	80	82	84	86
Yield	%	54	58	62	66	69	72	75	78
Area of good die	B mm²	26	33	40	48	57	67	78	92
Power density on chip	W/mm²	0.72	0.79	0.87	0.96	1.05	1.16	1.28	1.4
Lamp efficacy	lm/W	82	90	99	109	120	132	145	160
New light output	Tlm	1.6	2.3	3.4	5.0	7.2	10	14	20
Installed light output	Tlm	4	6.3	10	15	22	32	47	67

Table 1 describes a model in which lighting applications are divided into four groups, depending on light output. The “low” group includes most residential lamps, while most fluorescent replacements are contained in the “medium” category. Most streetlights and outdoor floodlights fall in the ‘high” and “super-high” brightness categories.

Note that the average efficacy refers to the whole lamp or luminaire under normal working conditions, and not just to the LED. The on-chip current density is taken to be 200 mA/mm² for low-power LEDs and around 700 mA/mm² for high brightness chips. The predicted product revenues ($26B) are at the high end of the forecasts cited above.

LED Market Penetration

Extrapolations from data gathered by the IEA for 2005 and the United Nations Environmental Program for 2010 suggest that the production of artificial light in 2014 will be around 180 petalumen-hours, from lamps with a light capacity of 60 teralumens (Tlm). The capacity of the LEDs produced in 2014 (1.6 Tlm) is thus 2.7% of total demand. The light output of all installed LEDs is now around 4 Tlm and so close to 7% of that of all sources.

The rate at which the market penetration grows depends on progress on several fronts:

- Increased LED efficacy leading to more light from each LED and lower lamp costs
- Solution of the droop problem to allow the LEDs to be driven at higher current density
- Reducing the under-utilization of available capacity
- Fewer rejects of processed chips
- New reactors to lower production costs as well as raising total capacity

Table 2 presents a scenario in which the available capacity, LED efficacy and current density increase by 10% each year, while the rates of under-utilization and defect production are reduced by 10%. The data refers only to lighting applications. It is left to the reader to decide whether this progress can be maintained and when saturation might set in.

Under this scenario the light output of the current installed base could be entirely replaced by LED lights by 2021and future production used for upgrades and market expansion.

The capacity addition that is contemplated here for 2015 corresponds to 100 traditional reactors or only 50 of the new Veeco EPIK700 systems. Thus the rate of acquisition of new MOCVD tools should be driven more by the resulting yield improvement and reduction in the cost-of-ownership, rather than the need to expand global capacity.

Conclusion

Substantial increases in the rate of investment in new manufacturing capacity may not be necessary to ensure rapid adoption of LED lighting, provided that R&D on LED technology and more efficient manufacturing techniques are pursued vigorously and that equipment is updated regularly to take advantage of this R&D work. ■

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Cost Saving Potential with Automation and Well Designed Processes

The manufacturing of modern LED luminaires and conventional fixtures has some similarities as well as some distinct differences that result in added challenges. Automation, in combination with a well-conceived product design and process combined with well-matched components, allows for economical manufacturing without compromising production quality and, consequently, reliable, high performance, and high quality luminaires. Olaf Baumeister, Head of Product Development and BJB-Automation at BJB GmbH, explains and discusses technical challenges, successful concepts and solutions.

LED is the technology of the future. This was impressively demonstrated at the world's leading trade fair for architecture and technology, Light+Building, in Frankfurt-am-Main in March 2014. LED luminaires for both indoor and outdoor applications dominated the range of products on display. The increased demand for LED solutions, however, also necessitates action from manufacturers because the prices which can be achieved on the market are falling. This can be offset to some extent by the LED chips, which are following the general decline in prices in the semiconductor industry - while simultaneously offering improved lighting parameters. In addition, the trend towards more LED luminaires is resulting in a demand for larger quantities, which, in turn, means a change in production requirements. The industry is currently between small-scale craftsmanship and industrial mass production.

This represents a challenge for the manufacturer, but is also an opportunity to put low-cost solutions on the market and gain market share. The question then arises of how the production of LED luminaires can be simplified, processes streamlined, and a consistent quality achieved while complying with the safety measures required when working with semiconductors. The competitiveness of the luminaire manufacturer ultimately depends on these factors.

A Consistent Approach to the Growth Market for LED Luminaires

In many ways, the requirements for the production of LED luminaires resemble those for the production of luminaires with conventional light sources: Automated production lines with wiring robots, such as the ADS systems, have long been in effective use. ADS stands for "Automatic Direct Wiring of Standard Components". Various components of the "modular machine system" can be combined to meet individual needs, i.e. can be adjusted to the exact requirements of the luminaire manufacturer. For small or medium batch sizes, there are individual stand-alone units and modular systems consisting of a loading and unloading station, wiring station and test station. At the other end of the spectrum, there are complete production lines with automatic assembly for very large quantities.

ADS product lines [1] for conventional technology have been adjusted to meet the requirements of LED processing and separate test stations have been added. For this type of processing, the individual stages are generally automated and the luminaires themselves optimized for automatic wiring, resulting in the manufacture of high-quality, low-cost products.

Even though the trend towards miniaturized luminaires in the last few years has meant that robot movements have had to become considerably more delicate, the wiring of LED luminaires represents a new dimension. It is also necessary to adapt the processes to the special requirements of the LED light source – i.e. a semiconductor component.

Due to the Semiconductor

When processing LED components with ADS systems, an important consideration is the avoidance of electrostatic discharge (ESD), a phenomenon which has previously

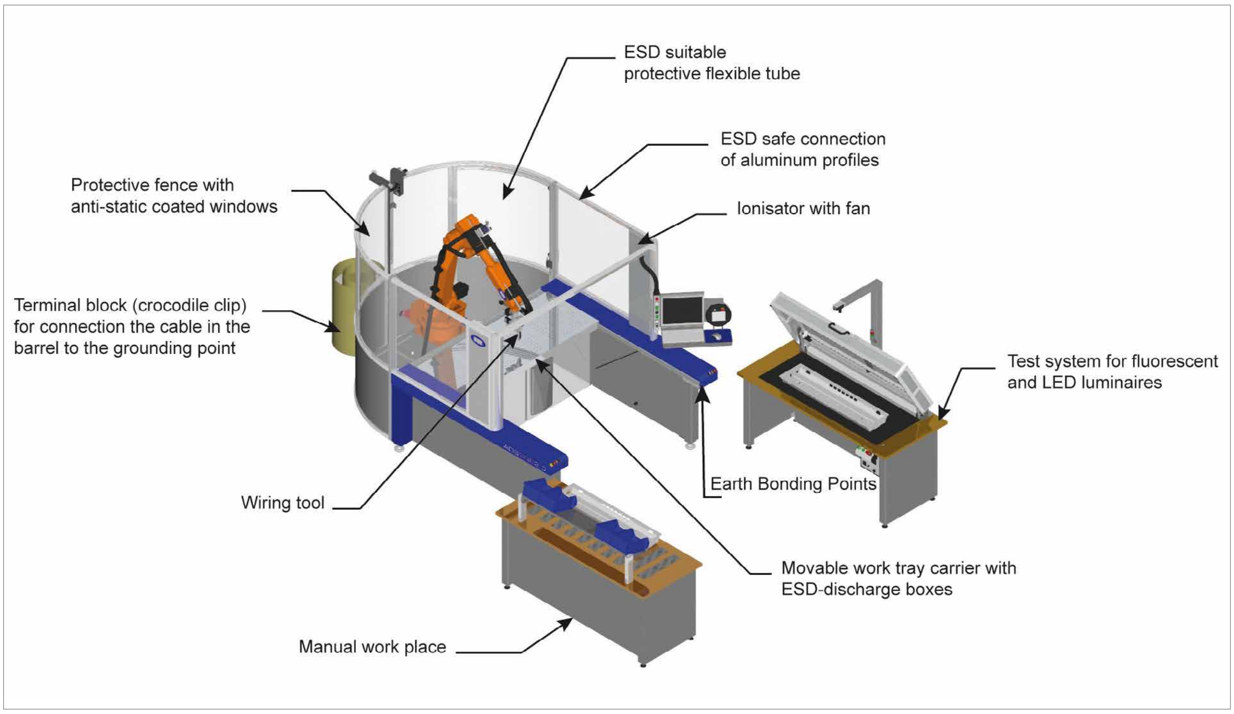

Figure 1:
The wiring robot and wiring tool are complemented by stations for test and assembly work. All components are specially designed for wiring LED luminaires with their special requirements, in particular with regard to avoidance of ESD

played a relatively low priority role in luminaire production. Electrostatic discharge (ESD) can damage LEDs or cause them to fail completely.

ESD is a spark or disruptive discharge resulting from a large potential difference in electrically insulating material that causes a very short, high-voltage electrical impulse. The potential difference usually results from a build-up of static electricity due to friction. Many everyday activities generate very high voltages. In the case of static discharge, a human being only notices electrical voltage from a level of about 3,000 volts. Semiconductor components can be damaged by as little as 100 V. The strength of the voltage impulse generated is very dependent on relative humidity as well as the intensity of the contact, the materials involved and the speed of separation [2].

ESD can damage LEDs so severely that they fail completely. As no more light is emitted, the LED remains dark during the optical inspection. In addition, it is no longer electrically conductive, so that other intact LEDs, which are connected in series, fail to light up. This type of failure is immediately recognizable. However, ESD damage can also have the effect that LEDs still emit light at first, but quickly become darker.

Such damage can be prevented by ESD-protective measures for machines and objects, as well as for the different stages of work. Earthing is an important measure. A fundamental rethink is also necessary for staff that has previously been involved with more robust lighting technology. For example, the wearing of ESD-protective clothing is essential. This includes a special wrist strap, conductive footwear and heel straps on both feet to ensure constant contact to the earthed floor.

Neutralization is also effective. An ionizer is used for this purpose. This generates billions of charged particles, which neutralize the static charge in an insulator.

Wiring systems also have to be designed to ensure that no electrostatic discharge can occur. ESD protection has top priority here and has to be implemented with particular reference to the standard DIN EN 61340-5 parts 1 and 3 [3, 4]. For this reason, the panes of the ADS protective enclosure are of statically dissipative polycarbonate. Special connecting elements provide an electrically conductive link between the aluminum profiles. In addition, the protective hoses that supply the wiring tool are made of conductive plastic (Figure 1). The wire that is to be processed is also earthed.

There is therefore a whole package of ESD measures to ensure that LED luminaires that leave the automated production facility are fully functional.

Handling Optimized for Speed

Standard wiring systems and test stations, which are of modular design and therefore custom-configurable, fulfill these requirements. Special tailor-made machines provide well-designed, task-specific solutions for automatic assembly, wiring and testing.

All process stages are designed to provide optimum flexibility and speed and run automatically [5]. The work piece carrier travels back and forth to minimize travel times for the operating personnel. So, while one person is manually removing the luminaire from the previous cycle, the other person is putting in place a prepared luminaire, i.e. the pre-assembled luminaire housing with LED modules, control gear and terminal blocks, for the following wiring cycle. There then follows the automatic wiring process with a 6-axis robot and a specially developed multifunctional wiring tool with cable feed (Figure 2).

The wire is transported to the wiring tool from a wire barrel that holds up to 12 km of wire. The wiring tool cuts the

Figure 2:
The wiring tool with cable feed enables precise wiring of LED luminaires even when space is extremely limited

necessary wires to length fully automatically (i.e. during the wiring process), strips the ends, and inserts them into the appropriate contacts in the luminaire. The pattern of wiring and the movement and configuration of the robot can be specified precisely. The sophisticated design of the wiring tool means that even inaccessible locations in miniaturized LED luminaire housings can be reached without difficulty.

Stations for test and assembly work complete the range. These machines boast an intuitive user interface. Separate offline software, which can be installed on a stand-alone computer, enables new wiring programs to be drawn up, or existing programs to be modified independently of the machine.

Comprehensive Test Procedures

In complex wiring systems, the LED luminaire that has been wired is automatically transported to the test station by the work piece carrier. There, detailed tests are carried out, some of which are prescribed for conventional luminaires in accordance with DIN EN 60598-1 [6] to ensure product safety, while others, e.g. according to DIN EN 62031 [7], apply specifically to LED light sources.

A suitable test bench is ESD-protected and has an earth bonding point for the operating staff. To enable the entire test procedure to be carried out (semi) automatically and unsupervised, or, alternatively, to provide visual protection, the bench is ideally also equipped with a safety hood that lowers automatically (in this case made of tinted polycarbonate). (Figure 3)

Other equipment available for the test station is a compact tester or a more convenient PC-based version in combination with a camera system, which examines the individual LEDs in a luminaire. This provides an objective result showing whether all LEDs are actually lighting up. An LED that remains dark may indicate ESD damage, a defective soldering point or a circuit interruption.

The camera-based procedure has clear advantages over a visual inspection by the operating personnel, for example by eliminating errors due to fatigue.

Protective conductor tests, insulation resistance tests and functional tests can be carried out with the basic version. The more intelligent version offers additional tests via the DALI/DSI interface and 1-10 V interface for control gear for luminaires with a dimming function. The result of the final test of the luminaire is displayed on the monitor and recorded for subsequent evaluation. The test result can also be stored in an Access or SQL database.

For Specified Operation

The DALI/DSI interface can also be used to combine the calibration of the control gear with the final test of the luminaire in one work stage using the intelligent system. This ensures that the LED modules are subjected to the "right" constant current - because there are now universal converters that are not designed for standard values like 350 mA, 700 mA or 1050 mA, but cover a wide constant current range.

In addition to this direct "digital" calibration during testing, there is the possibility of a mechanical-electrical calibration with a resistor. For this purpose there is a specially developed "Set'n'Drive resistor", which can be inserted on the secondary side of the LED converter once wiring has been completed. This can be done either manually or automatically using the wiring tool of the ADS wiring system. The three gripping positions on the housing enable insertion to be carried out at any angle. For automatic processing, the Set'n'Drive resistors are correctly pre-positioned in trays in the area of the work piece carrier. This also ensures an error-free calibration of the control gear.

Components for New Requirements

Cost saving in automated LED luminaire production can be improved even further by the use of standard

Figure 3:
The ESD-protected test bench with its safety hood of tinted polycarbonate, which lowers automatically, provides visual protection or, alternatively, the possibility of allowing the entire test procedure to be carried out unsupervised

Figure 4:
The SMD terminal block for rear-side wiring speeds up production of luminaires with control gear on the rear side of the mounting plate, as it is not necessary to turn the luminaire during assembly

components. To maintain a position as a capable partner to the lighting industry in the changeover from conventional lighting to digital lighting and cope with the resulting challenges, it is necessary to have an interdepartmental innovation team with representatives from Research and Development, Product Management, Automation, Engineering, Quality Assurance, Sales and Marketing. Their role is to develop ideas based on their many years of experience, in particular regarding the extensive global sales network and their direct access to users in the luminaire production sector. Tailor-made ADS systems are based on the analysis of the tasks to be performed as well as the luminaire to be manufactured and how its layout can be improved to make it more suitable for automation purposes.

Only a systematic approach, as far as possible from the customer's perspective, leads to LED-specific solutions. Expertise in "conventional" connection technology combined with knowledge in the field of automated luminaire wiring produce well-designed components and systems. The objectives are simplification and economic rationalization while maintaining a constant high quality. A prerequisite is that components have to be adapted to the specific characteristics of the LED light source – such as extremely slim design - and fulfill the requirement for consistent thermal management. Such components then provide new freedom in luminaire design, resulting in significant added value for the luminaire manufacturer.

Components that save time and money through easier handling, for example through plug-in connection instead of soldering, have an equally beneficial effect. Without soldering, the components are not exposed to thermal stress during assembly. This, in turn, minimizes the risk of failure. Plug-in connection is also environmentally friendly as no soldering fumes are released and there is no exposure to pollutants. Ultimately, energy consumption is also minimized.

Delicately Designed Terminal Blocks with Variants

Terminal blocks and connectors precisely geared to the requirements of the LED age have the potential to improve and accelerate the automated production of delicate LED luminaires. SMD terminal blocks for rear-side wiring are an example. These are particularly advantageous in the case of luminaires with control gear on the rear side of the mounting plate (Figure 4). Unlike conventional terminal blocks, these do not require the luminaires to be turned during assembly. The omission of this time-consuming process speeds up production time considerably. Because conductors, terminal blocks and control gear are now hidden "elegantly" behind the LED module, this intelligent type of wiring has the added advantage that individual LEDs are no longer obscured by untidily laid cables which impair their light emission. Due to the slim design, reflectors, optical and lens systems can be attached directly above the module.

With their slim design and plug-in technology, Board-to-Board connectors (B2B) represent an equally easy and efficient solution. They enable LED modules to be combined both mechanically and electrically to form endless light band fittings. No additional wiring is required, thereby reducing disturbing shadow formation. This concept requires no screws or tools, which also simplifies the installation process.

Use of these versatile connectors results in the LED luminaire having a "tidy" layout that is consistent with the characteristics and requirements of the light source itself and the prerequisites for low-cost automated production (Figure 5).

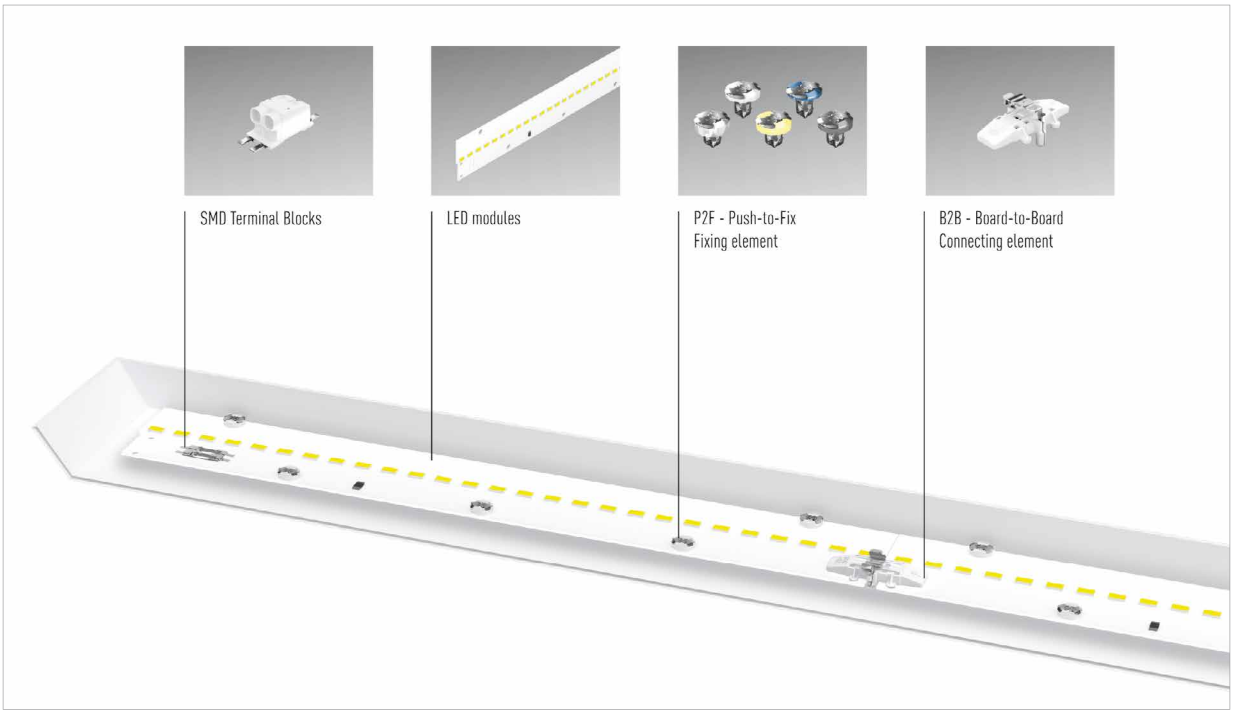

Figure 5: The extremely compact connectors which have been specially developed to meet the requirements of delicately designed LED luminaires, such as SMD terminal blocks for rear-side wiring, Board-to-Board connectors or Push-to-Fix elements, minimize conductor requirements and ensure a "tidy" layout which is suitable for automation

Figure 6: Consisting of a metal spring and elastic silicone, the Push-to-Fix element ensures a large area of contact between the circuit board and the luminaire housing, resulting in excellent heat dissipation

Figure 7: The P2F fixing element can be installed manually or with a special setting device, which is equipped with an automated feed system in order to speed up the process even further

Innovative Connection Technology with Multiple Benefits

The Push-to-Fix element (P2F), which can be used to fix LED modules and components, goes one step further. This represents a significant improvement over screw fixing and has established itself on the market in a very short time by providing considerable added value, not only in the assembly process, but also during luminaire operation. Consisting of a metal spring and elastic silicone (Figure 6), the P2F board fixing element exerts a constant pressure of 10 N and ensures excellent heat dissipation due to the large area of contact between the circuit board and the luminaire housing, with no bending. This is an important aspect, which has a significant influence on the life of LED luminaires [10].

Due to its dimensional stability and temperature resistance, resulting from its virtually floating method of connection, the silicone ring can offset tolerances or compensate for thermally induced length variations in a component fixed in this way – in the case of a 560 mm long circuit board, this can be as much as 1 mm. The forces exerted during the automatic wiring of SMD terminal blocks can also be effectively absorbed by using the P2F fixing element.

The electrically insulating connection to the circuit board is shock and vibration resistant. There are five variants of the Push-to-Fix element, with different colored silicone rings, to cater for the usual package thicknesses of LED module and luminaire housing of between 1.5 mm and 3.6 mm.
This fixing element is installed manually or by means of a special setting device, which is equipped with an automated feed system to accelerate the process even further (Figure 7). As well as the technical benefits it offers, the P2F concept has a considerable number of other advantages over the screw - it can perform several tasks at the same time and is quick and easy to install.

Conclusion

Basically, as experience in the conventional lighting sector has already shown, what is required to produce an optimum result is the combination of an LED luminaire layout suitable for automation, the appropriate connection components, and a tailor-made ADS system. In the "LED age", what constitutes added value in an LED luminaire designed to be suitable for automation is the ability of a manufacturer to be faster, more efficient and less expensive, while at the same time providing superior quality. Automation delivers reproducible results. ■

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Managing Manufacturing and Supply Chain Challenges in LED Luminaire Design

Today's luminaires are often complicated lighting systems and have a wide range of applications from in-home luminaires and retail to very high power outdoor lighting. This causes several challenges in both design and manufacturing. Some of these problems may have already been solved by design and manufacturing firms having expertise with LED luminaire design and manufacturing. Gelston Howell, Senior Vice President at Sanmina explains how to manage some of these design, manufacturing and supply chain challenges by using examples.

While large luminaire companies have outsourced production to contract manufacturing firms for some time, these companies are now outsourcing product design as well. Contract manufacturers and design firms now provide custom design, component selection and supply chain management services as well as manufacturing and test expertise to enable LED lighting OEMs to overcome the technical challenges associated with bringing LED luminaires to market. Moreover, these luminaire companies in some cases depend on EMS (Electronic Manufacturing Services) companies to provide complex technology solutions for luminaire designs to solve unique challenges. For example, unique heat sinking technologies have been developed by EMS companies with expertise in PCB (Printed Circuit Board) technology and thermal design, leveraging experience from other industries in the design of high power LED luminaires. Luminaire companies are often surprised at the depth of technical expertise and range of services provided by EMS and design firms. This design experience, along with global supply chain and manufacturing services, provide LED luminaire companies with a complete solution for complex LED light product design and manufacture.

Design and Technology Challenges with LED Lighting Products

Heat dissipation, design for cost and manufacturability, along with test systems development are some of the most common issues luminaire companies face with new products.

Heat dissipation is extremely important for LED luminaires. A critical issue for LED lighting and cooling is the very high heat fluxes coming from the LED semiconductor devices. Thermal engineering, simulation and analysis can be complex for some luminaires. Design firms and EMS companies can leverage years of experience with thermal design for high performance computing and telecommunications products, at times incorporating some of the same thermal dissipation techniques. For some products, careful design of the PCB and product housing using passive heat dissipation techniques will help. The hot spots in an LED luminaire are normally located in the DC-DC converters and the LED components. Maximizing the size of thermal pads laminated onto the PCB in the locations of the hot spots will route heat away from the components. Providing thermal pathways in the form of thick planes of copper in the PCB will allow heat to be conducted away from hot spots. Maximizing the metal to metal transfer from the PCB to the aluminum outer product casing provides effective heat dissipation allowing the components to operate in a way that maximizes the life of the product. Finally, outer casing design using aluminum formed to allow maximum heat dissipation through the product housing to the air will eliminate the need for separate heat dissipation systems. This ensures that heat can be quickly removed from individual LED components, increasing the life of these products. Figure 1 shows a thermal analysis for an original LED product design where the hotspots were in excess of 100°C. In this case the housing was redesigned, leveraging PCB technology and thermal engineering experience from industrial products designed previously. The resulting thermal performance of the improved design can be seen in figure 2, achieving peak temperatures of less than 70°C.

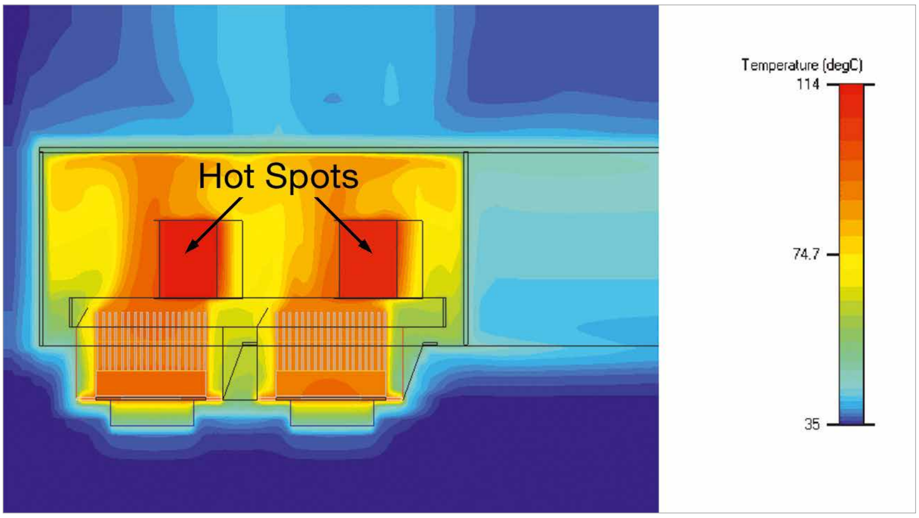


Figure 1: Thermal analysis of LED Lighting System showing initial hotspots in excess of 110°C

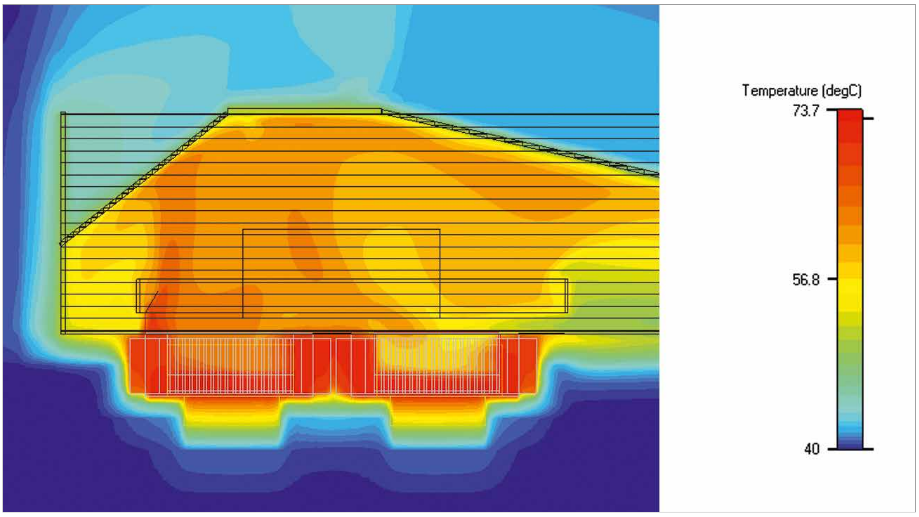


Figure 2: New design incorporating thermal engineering on the PCB achieves peak temperatures of < 70°C

Retail and exterior LED lighting applications each present unique design challenges. Different areas in a supermarket will require different color LED lighting systems to enhance product appearance. For example, the fresh produce will benefit from being lit with slightly different color hues depending on the color of the fruit or vegetable.
The LED lighting can be designed so that this color temperature (i.e. the hue) can be controlled remotely. Both retail and exterior lighting applications need different numbers of LED lighting units depending on the lighting intensity required and the size of the area to be covered. Designing one PCBA (Printed Circuit Board Assembly) to accommodate different LED colors and numbers of LEDs allows the color variation and quantity to be scaled without a huge number of unique PCBs. In this same design, the luminaires and PCBs were designed to be modular and connected with one another in nearly any number, thanks to the inclusion of a standard power rail going through all luminaires. The elimination of multiple PCB types dramatically increases flexibility and reduces costs of manufacturing and inventory.

Where large volumes of LED components are used in exterior high power or retail LED lighting applications, the issue of variation in the LEDs (even those with the same part number) needs to be addressed. LED components vary by color temperature (light wavelength) and light intensity. In a large scale installation such as exterior building lighting or a supermarket it is important to ensure a consistent color temperature and intensity. The larger the lighting installation the more complex this challenge becomes. Assembly processes must be designed to carefully select LED components for placement in specific areas of the PCB according to the LED manufacturers binning rules. Compliance with the rules should

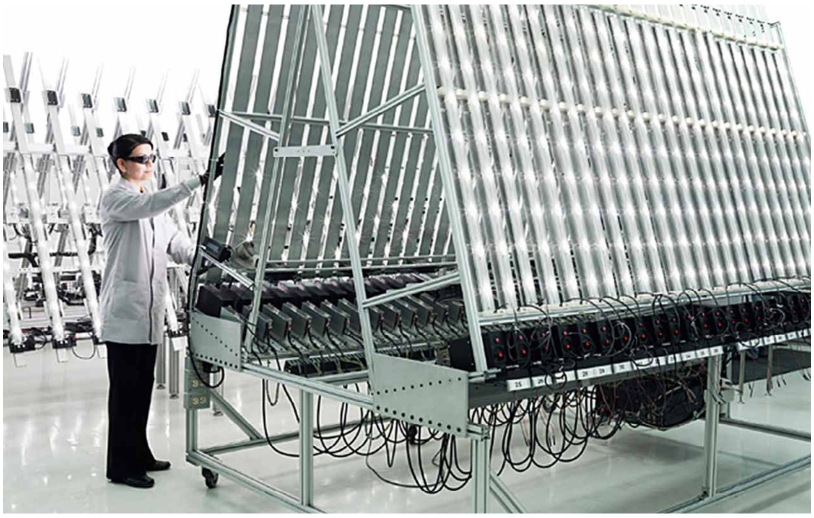


Figure 3: LED functional test and burn-in facility for LED luminaires

eliminate the potential for imbalanced light and shadow. Software is required to manage this selection and placement process when large quantities of LEDs are involved.
Functional test processes typically verify that a finished product is performing to specification. Designing the functional test process to measure color intensity, color temperature and emissive chromaticity will ensure that the finished product meets specification and that balanced light is achieved in compliance with the manufacturers binning rules. Optical sensor technology is integrated into functional testers to make these measurements. The testers are implemented in a black box to eliminate the interference from ambient light. This component selection and test process, coupled with a design that optimized the distance between LED sources, will result in a product with the desired color hue, no shadowing and balanced light.

The Unique Issues of Manufacturing LED Lighting Products

Managing the LED binning process, high volume manufacturing automation and managing stress during the manufacturing process are some key challenges in manufacturing LED lighting systems.

Lighting building exteriors and fitting out large retail stores with LED lighting requires large numbers of LED lighting products. Achieving high quality and reliability in high-volume can be helped by the sensible application of manufacturing automation.
The sub-assembly and finished product functional test process is one area where process automation can provide a significant return on investment.
The inherent variability in intensity and color temperature in LEDs, together with requirements for testing in environments where ambient lighting can be controlled, necessitate a custom automated test and burn-in solution. Engineers developed such a solution to automate, test and burn-in up to 100 LED luminaires at a time.
The system monitors the intensity and wavelength of light from the luminaires and provides pass / fail feedback to production staff, as well as an automated electronic archive of all test results.

LED components are particularly susceptible to stress fractures which can be induced during manufacturing. When high volumes of LED lighting PCBAs and modules are manufactured, the probability of inducing stress related failures can increase. Sometimes, these fractures are very small and cannot be seen by a simple visual inspection, but they can shorten the expected lifetime or reliability of the finished product. Careful design, planning and monitoring of the manufacturing processes eliminate the possibility of stress induced failures. The design of carriers used during manufacture, handling equipment and monitoring equipment are all important. Using LEAN principles in the design of manufacturing lines can help minimize the path products need to travel. This reduces opportunities for handling and vibration to cause damage. Some processes used in PCBA manufacture such as de-penalization can cause shock, stress or vibration to LED components. Traditional methods of de-penalization such as scoring, snap-off or routing are sufficient for many components, however the micro lens and ceramics materials in LEDs require more sophisticated de-penalization.
One way to eliminate the potential for such damage is to use a numerically controlled milling robot to separate the PCBAs from the panel. All of these factors are taken into consideration when designing the manufacturing processes and tooling for high volume LED lighting products. Manufacturing control systems that provide component, sub-assembly and product traceability together with stress measurement monitoring are also an important part of the manufacturing process design.

Managing the Complex Supply Chain

In the LED market space it is estimated that there are over 2,000 component providers and manufacturers of LEDs, packages and luminaires in China alone. The LED luminaire supply chain includes many of the traditional suppliers, such as LED, driver and integrated circuit companies. It also includes specialist LED and lighting companies as well as suppliers of custom components such as extruded aluminum, plastic parts and PCBs. Supply chain design and management is really a cross-functional and concurrent process that starts during design and continues throughout the product lifecycle. There are many aspects to the supply chain design including supplier capability assessment, component engineering analysis along with commercial considerations.

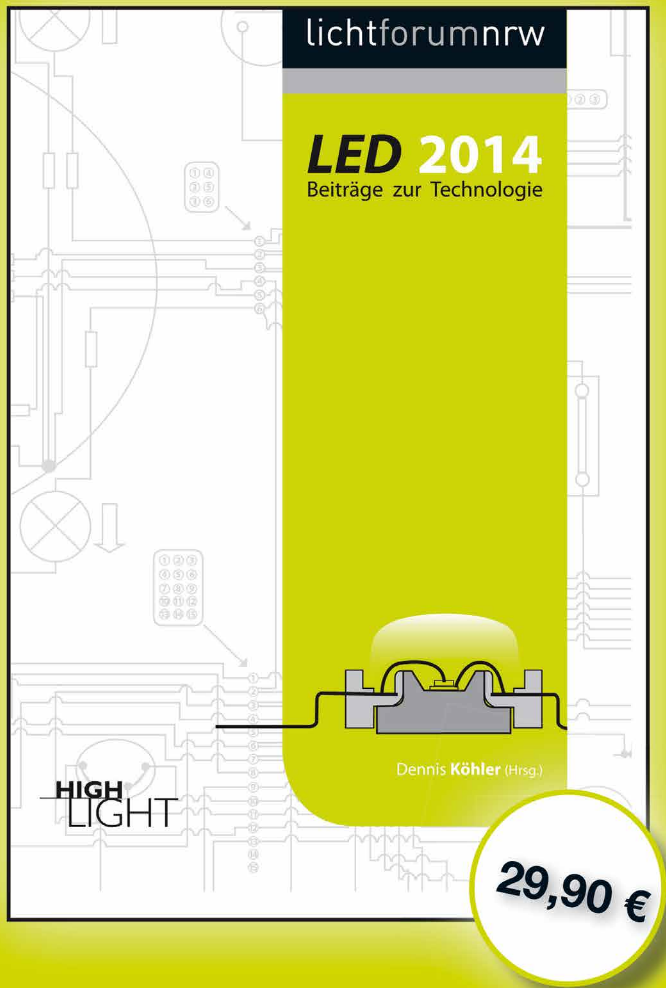
Supplier capability assessment is particularly important for the custom components included in a design. Access to and knowledge of standard electronic component manufacturers and products is important. However, it needs to be combined with a careful assessment of the suppliers who will provide the custom components. Partners with in-house capabilities such as PCB design and fabrication, precision machining, metal fabrication, aluminum extrusion and plastic injection molding help simplify the supply chain.

Component engineers analyze a bill of materials from a technical, cost and risk mitigation standpoint. Alternative components are compared to determine suitability based on the overall product specification and component cost at various volumes. Risk analysis is also undertaken to identify components where only a single source is available. Multiple sources for the same component allow better risk management of the supply chain both at the design stage and volume production. In some EMS companies the component engineers also have access to applications engineers at the component manufacturer and can assess knowledge about the stage of the component in its own lifecycle; that is, is that component likely to become obsolete. This process allows component engineers to make technical recommendations to design engineers and commercial recommendations to supply chain management.

Supply chain management should be concerned not just with pure component cost. Other key factors such as risk mitigation and flexibility are very important when building a robust supply chain. Choice of supplier and selection of dual or multiple sources should take into account, along with the end market geography for the luminaire, the logistics and import/export costs and duties throughout the supply chain. All of these elements contribute to the total landed cost. Shorter lead-times and multiple component sources allow a supply chain to respond to the revenue opportunities associated with unforeseen demand. This flexibility is important in the LED lighting market where the selection of the luminaire vendor may depend on their ability to deliver in high volume on short notice. A rigorous analysis of total landed cost together with lead-time analysis and the creation of multiple sources for critical components will result in a much more robust supply chain.

Conclusions

OEM LED lighting companies seek a fully integrated solution for manufacturing, with design services and a global supply chain. Working with partners having experience with LED luminaires is essential. In addition, if they also have experience in other relevant industries and technologies, these partners can provide differentiated competitive advantages in product performance, cost, time to market and global supply chain. ■



Advanced Optical Plastics Materials for LED Lighting Applications

Across a range of lighting solutions, Light Emitting Diodes have emerged as the clear choice for industry and consumers alike. Government regulations and consumer preference for more environmentally-conscious, energy-efficient products have caused manufacturers to develop solutions for the marketplace that offer new levels of energy efficiency, durability and long life. While the technology has evolved, so have the materials that go into the finished product. Claude Van Nuffel, Eric Wu, Peter Jackson and Marta Sans Peña from Styron LLC discuss versatility and one-of-a-kind properties of plastic – especially polycarbonate and polycarbonate blends – and why they have become the "materials of choice".

The needs of manufacturers and fabricators for LED lighting components are extremely complex and typically include a variety of considerations such as:

- Protecting the costly LED light source
- Ensuring excellent ignition resistance
- Providing for long-term heat stability
- Meeting industry regulations and standards
- Accommodating movement and jarring
- Balancing clarity and diffusion
- Meeting thermal requirements
- Offering great design freedom and light weighting of parts

Very few materials can fulfill these needs. Polycarbonate and polycarbonate blends are now used in a variety of LED applications because they have the balance of properties to meet these demanding and varied requirements. The latest developments in managing this critical performance triangle between optimal light transmission, meeting haze requirements and flame retardancy will be discussed. Also shown will be how these developments resulted in the commercialization of new grade resins like Styron's EMERGE™ PC 8830LT Advanced Resin. At the same time, the current state-of-the-art grades, and considerations when working toward UL 94 certification of V-0 (at 1.0 mm) will also be discussed.

Managing the Critical Performance Triangle

One crucial challenge in current resin developments in LED applications is achieving high flame retardancy (ignition resistance) in combination with the necessary optical properties, e.g. high transmission combined with the needed level of haze (e.g. low or high diffusion depending on the targeted application).

An LED can be a very bright, unidirectional source, and lamp/ luminaire manufacturers need materials

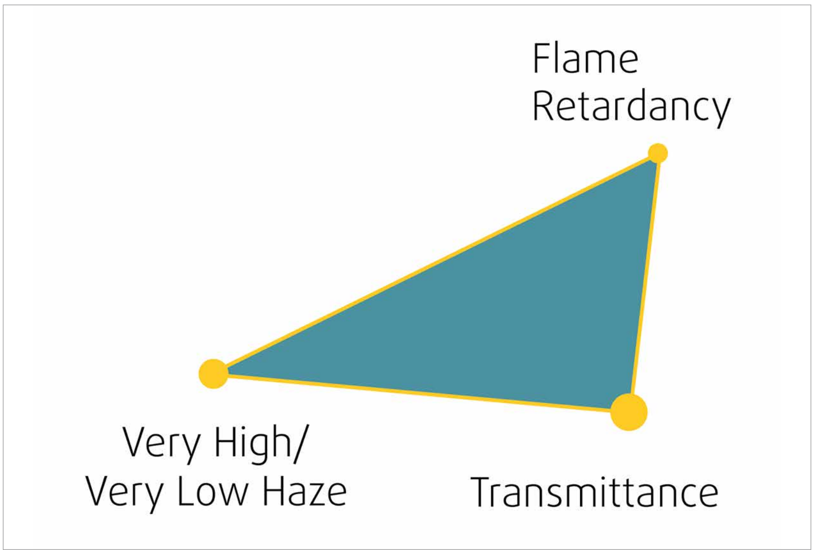


Figure 1: **Achieving high flame retardancy in combination with the necessary optical properties**

Fact Sheet on UL94 Requirements

UL 94 V-0

For UL 94 V-0 and 5VB evaluation, flame retardancy is tested on a specimen with a length of about 125 mm, a width of about 13 mm and a thickness of 1.0 mm (for UL94 V-0) or 2.5 mm or 3.0 mm (for UL94 5VB).

The specimen is mounted with the longest part facing vertically and is supported with its lower end about 10 mm above a burner tube. A blue flame of 20 mm in height is applied to the center of the lower edge of the specimen for 10 seconds and then removed. If burning ceases within 30 seconds, the flame is applied for an additional 10 seconds.

In order for the material to meet the UL-94 V-0 requirements

- the specimen may not burn with flaming combustion for more than 10 seconds after application of the test flame
- total burn time for a set of 5 specimens may not exceed 50 seconds
- the specimens may not burn with flaming or glowing combustion up to the holding clamp
- the specimens may not drip flaming particles that ignite a dry absorbent surgical cotton placed 300 mm below the test specimen
- the specimens may not have glowing combustion that persists for more than 30 seconds after the second removal of the test flame

UL 94 5VB and 5VA

The flame ignition source for the 5VB and 5VA standard is approximately 5X more severe compared with the flame ignition source for the V-0 standard test.

For UL 94 5VB, flame retardancy is tested on a specimen with a length of about 125 mm, a width of about 13 mm and a thickness of 2.5 mm or 3.0 mm

The bar specimen is supported in a vertical position and a flame is applied to one of the lower corners of the specimen at a 20° angle. A flame of 125 mm height is applied for 5 seconds and is removed for 5 seconds. The flame application and removal is repeated five times.

In order for the material to meet the UL 94 5VB requirements

- the specimens must not have any flaming or glowing combustion for more than 60 seconds after the five flame applications
- the specimens must not drip flaming particles that ignite the cotton
- the specimens may exhibit burn through (a hole)

For UL 94 5VA, flame retardancy is tested on square plaques which have a thickness of 2.5 mm or 3.0 mm. A first set of 5 specimens is conditioned for 48 hours at 23°C and 50% relative humidity. A second set of 5 specimens is conditioned for 7 days at 70°C.

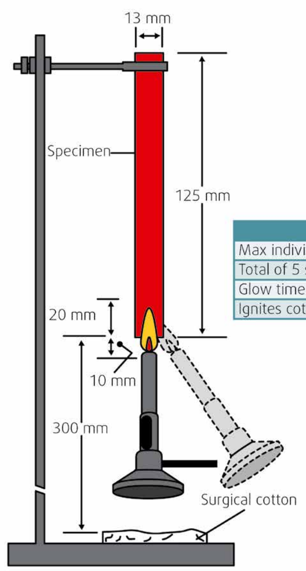
The procedure for plaques is the same as for bars (UL 94 5VB) except that the plaque specimen is mounted horizontally and a flame is applied to the center of the lower surface of the plaque.

In order for the material to meet the UL 94 5VA requirements

- the specimens must not have any flaming or glowing combustion for more than 60 seconds after the five flame applications
- the specimens must not drip flaming particles that ignite the cotton
- plaque specimens must not exhibit burn through (a hole)

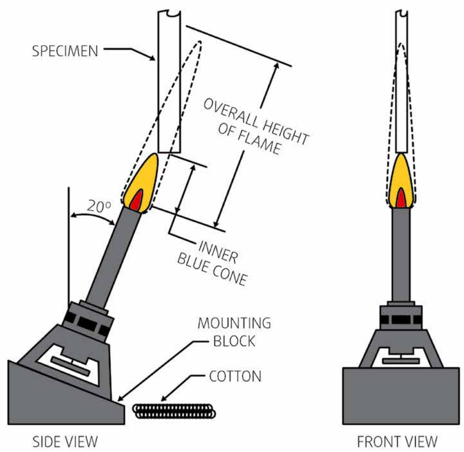
Because the UL 94 5VB and UL-94 5VA tests employ a more severe flame ignition source and do not allow for dripping of any flaming particles, these tests are generally more difficult to pass compared with those for the UL 94 V-0.

UL 94 Test Setup Drawings



	V-0	V-1	V-2
Max individual burn time	<10 s	<30 s	<30 s
Total of 5 specimens	<50 s	<250 s	<250 s
Glow time after 2nd ignition	<30 s	<60 s	<60 s
Ignites cotton	No	No	Yes

Figure 1 + Table: **UL94 test set up for V ratings**



Rating	5VA	5VB
Burn and Glow Time, sec	≤60	≤60
Flaming Drips	No	No
Burn-through on Plaques	No	Yes

Figure 2 + Table: **UL94 test set up for 5VA and 5VB ratings**

that either make it possible for the light to shine directly through a surface for maximum brightness (high transmission, no diffusion), or create a uniform light distribution with no evidence of the light source (high haze, high diffusivity), for a more diffused effect. Adjusting material properties is often a careful balance because additives for light diffusion can impact light transmission, flammability rating and other properties. On the other hand, various technical routes to achieve outstanding flame ratings, will inherently not allow for good light transmission.

It is the lens or the enclosure of the LED source that plays a primary role of the amount of light that is transmitted or diffused. While achieving optical properties is of primary importance, requirements for flame retardancy also have to be met to accommodate these high-powered LED light sources that can operate at temperatures as high as 80-110°C. For lower voltage applications using Class 2 power sources with UL 94 HB and V-2 flammability requirements, polycarbonate, acrylics and styrenic-based resins such as SAN can be considered as materials for lenses, covers, and optics. However, for more demanding LED lighting applications where Class 1 power sources are used, the material requirement for optics and lenses is UL 94 V-0 and, in some cases, even UL 5VA.

Industry requirements are continuously increasing up to a point where a variety of light applications need to meet UL 94 V-0, 5VB and 5VA standards at reduced lens thicknesses. Since lighting applications are increasingly becoming thinner and thinner, customers are looking for grades that have the transparency of a 'neat' polycarbonate while offering good flame retardancy at a thickness of 1 mm. Furthermore, it is desired that these formulations are bromine- and chlorine free.

R&D Track to Create Flame-Retardant Polycarbonates with High Total Luminous Transmittance

Current state-of-the-art polycarbonate compositions have been employed for various applications with balanced flame retardancy and/or transparency requirements. Examples of such polycarbonate compositions are described in Table 1. As shown in Table 1, the compositions meet a wide spectrum of property balances which find broad acceptance in the lighting market. However, there is need of further optimization, for instance, for transparent formulations that meet UL 94 V-0 at 1.0 mm, as well as for formulations which offer a high level of light transmission combined with a high level of light diffusivity, still meeting UL 94 V-0 at 1.0 mm.

Furthermore, there are no such formulations available which meet both UL 94 V-0 at 1.0 mm and 5VB or 5VA at 2.5 mm or 3.0 mm. Thus, there is a clear need for materials that offer improved flame retardancy combined with strong optical properties.

Defining the application needs

Increased requirements emerging from customer projects have indicated a clear need for a highly-transparent, flame-retardant polycarbonate product, which offers high total luminous transmittance, very low haze and good flame retardancy (and therefore meets the requirements for one or more of the following UL 94 standards: V-0 at 1.0 mm, 5VB at 2.5 mm or 3.0 mm, or 5VA at 2.5 mm or 3.0 mm.

At the same time, customers also require a flame-retardant polycarbonate composition that has a high level of haze and good flame retardancy (achieving the requirements for one or more of the following UL-94 standards: V-0 at 1.0 mm, 5VB at 2.5 mm or 3.0 mm, or 5VA at 2.5 mm or 3.0 mm).

Development track followed

Relative to transparent formulations, starting from the products disclosed in Table 1, it needs to be investigated whether a flame-retardant additive package can be developed to meet the more stringent flammability requirements of UL 94 V-0 and 5VB/5VA while maintaining transparency performance.

Table 1: **State-of-the-art (bromine- and chlorine free) polycarbonate compositions and their relative results in performance tests, key in today's LED market (n.a.: not available; MFR: melt flow rate)**

GRADE	MFR RANGE g/10'	V-0 at	5VB at	5VA at	Visual appearance
EMERGE™ PC 84X0	3-31	3.0 mm	n.a.	n.a.	transparent
EMERGE™ PC 83X0	3-22	2.5 mm	n.a.	n.a.	transparent
EMERGE™ PC 82X0	3-31	1.5 mm	3.0	3.0	opaque
EMERGE™ PC 81X0	3-15	1.0 mm	2.0	3.0	opaque
EMERGE™ PC 84X0LT	3-8	1.5 mm	n.a.	n.a.	transparent

Table 2: **Specific requirements defined for PC formulation with high total luminous transmittance**

Specific requirements defined for PC formulation with high total luminous transmittance		
Total luminous transmittance of about 90.0% or more at a thickness of 1.0 mm	A haze of about 1.0% or less at a thickness of 1.0 mm	
UL-94 standards: V-0 at 1.0 mm	UL-94 standards: 5VB at 2.5 mm or 3.0 mm	UL-94 standards: 5VA at 2.5 mm or 3.0 mm
Specific requirements defined for PC formulation with high total luminous transmittance and high haze		
Total luminous transmittance of about 50% or more at a thickness of 1.0 mm	A haze of about 50% or more, preferably about 70% or more, and most preferably about 80% or more at a thickness of 1.0 mm	
UL-94 standards: V-0 at 1.0 mm	UL-94 standards: 5VB at 2.5 mm or 3.0 mm	UL-94 standards: 5VA at 2.5 mm or 3.0 mm

There are a number of challenges to overcome for the development of such flame-retardant polycarbonate compositions.

Meeting the more demanding flammability requirements
- Maintaining the high level of transparency (total light transmission) as for 'neat' polycarbonate
- Limitation to bromine- and chlorine free flame-retardant packages

Each of these challenges brings with it limitations in the number of design parameters for the formulations.

First, in order to meet the more demanding flammability parameters, one needs to investigate what can be achieved using the state-of-the-art flame retardant packages. Therefore, it is necessary to have a good understanding of how the flammability tests are conducted and what flame-retardancy mechanisms help to meet the desired performance.

A brief description of the UL 94 test criteria, as well as the UL 94 test set-up (figures and tables) is provided.

Designing for UL94 Compliance

It is clear that there are two key elements in the UL 94 test requirements as explained in the fact box:
- Short burn times
- Preventing flaming drips

In order to have short burn times, a highly effective flame retardant package is required. Many flame retardants are available, but only a few are effective in polycarbonate. These are bromine- and chlorine free flame retardants; hence there remain only a few candidates for flame retardants that shall be discussed in detail.

The most important three categories of flame retardants for rendering polycarbonate flame retardant are:
- flame retardants which contain phosphorous
- additives containing sulfur
- siloxanes

However, phosphate esters are rarely used in plane polycarbonate because of partial loss of clarity, tendency to stress-cracking and reduced hydrolytic stability. Typically, high concentrations (>4wt%) are also required to make polycarbonate flame retardant, which causes embrittlement of the polycarbonate. This eliminates the phosphates from the list of potential candidates.

Flame Retardants containing sulfur are typically referred to as charring salts. These are reported to be quite effective even at very low loadings (<0.2 wt%). But, it is also disclosed that they may cause some haziness.

Various siloxanes are also potential flame retardants for polycarbonate. However, little is disclosed on their effective concentrations and on how they may impact transparency.

To prevent flaming drips, effective flame retardants which cause short burn times will also contribute.
In many cases, however, PTFE [poly(tetrafluoroethylene)] will be used as an additional anti-drip agent. Unfortunately, the addition of PTFE will cause the polycarbonate to become opaque.

Therefore, PTFE should be left out of the composition when a high level of transparency is desired.

Another parameter affecting the dripping tendency of polycarbonate is its melt strength. A higher melt-strength will help to prevent flaming drips. Melt strength is controlled by the molecular weight and the degree of branching of the polycarbonate.

For the high haze (or Light Diffusing) polycarbonate compositions, light diffusing agents are typically added. There are a number of different light diffusing agent technologies available. However, many have a negative effect on the flammability performance, for example, core/shell acrylic rubbers (EP634445B1) or cross-linked PMMA (polymethylmethacrylate) particles.

Hence, from a composition point of view, there are a number of variables to be considered, such as:
- Type of primary flame retardant
- Type of secondary flame retardant
- Level ratios of flame retardant types
- Type of light diffusing agent
- Level of light diffusing agent
- Molecular weight of the polycarbonate

As discussed above, key property requirements are the flammability performance (UL 94 V-0, 5VB and 5VA) at the various sample thicknesses and the light properties (transparency [total light transmission], % haze, light diffusivity, etc.), also as a function of thickness.

In addition:
- Flammability performance is determined according to the findings above.
- Determination of transparency and % haze is done on injection-molded plaques.
- Transparency is determined by total luminous transmittance as measured according to ASTM D1003, at a thickness of 1.0 mm.
- Haze is measured according to ASTM D1003 (standard test method for haze and luminous transmittance of transparent plastics), also at a thickness of 1.0 mm, when the haze is about 30% or less. If haze is greater than 30% then it should be tested in accordance with Practice E2387 (ASTM E2387 Standard Practice for Goniometric Optical Scatter Measurements).

In the evaluations, the following components were used:
- Primary flame retardant
  - Type A
  - Type B
- Secondary flame retardants
  - Type C
  - Type D
- Light Diffusing Agents
  - Types E, F, G, H & I
- Polycarbonate resins
  - CALIBRE™ 200-3: High Molecular weight Polycarbonate
  - CALIBRE™ 200-22: Low Molecular weight Polycarbonate

Compositional Parameters – Influence on Key Property Requirements for Transparent Applications

As indicated above, there are many compositional parameters that affect the key functional requirements on flammability, transparency and haze. Their effect was investigated in a series of experiments. Once the effects were elucidated, compositions meeting all key functional requirements could be defined with further experimentation.

Compositional parameters studied are the type of flame retardants, the level flame retardant, and the molecular weight of the polycarbonate.

In a first series of experiments, the performance of the flame retardants was investigated, as well as the effect of concentration levels. It was demonstrated that amongst the flame retardants, types A and C performed the best in terms of flammability, total light transmission and % haze performance.

Furthermore it was found that additional levels of both components needed to be optimized and limited to a narrow concentration range in order to maintain the desired flammability rating, as well as the high level of total light transmission and the low level of % haze.

A selection of the performed experiments, demonstrating the above findings, is reported in Table 3.

It is clear from the experiments from Table 3 that the requirements on level of total light transmission and % haze can be met and that also UL 94 V-0 and 5VA/5VB performances are excellent, but that the required flammability performance at the lower thicknesses (V-0 at 1.0 mm and 5VA at 2.5 mm) is not achieved.

In subsequent experiments, combinations of the flame retardant A and C are evaluated. Different polycarbonate feedstocks are also used. Flammability and light properties were measured on these materials. Results are reported in Table 4.

It is demonstrated that when flame retardants A and C are used in combination with each other, all required properties on flammability, total light transmission and % haze are met, when the low MFR polycarbonate feedstocks are used. When the high MFR PC feedstock is used, the required flammability performance is not achieved.

This illustrates the need to choose a careful selection from particular combinations of various flame retardants with different chemistries, and at very well defined concentrations, and limit the polycarbonate Melt Flow Rate to lower values, in order to obtain the optimal property balance required for LED applications.

In a subsequent effort, light diffusing compositions are to be developed which have a similar flammability performance, and offer a combination of high total light transmission and high light diffusivity.

It has been explained above how the flammability performance and the total light transmission are quantified. For the quantification of light diffusivity, the % haze measurement can also be used. An even more accurate measurement technique is the determination of the D50 angle.

D50 is the angle at which the amount of transmitted light is 50% of the amount of the transmitted light at angle 0°. This can be measured using a variable angle photometer such as GP-200 from Murakami Color Research laboratory. It should be emphasized here that for a perfect diffuser, the D50 angle is 60°, which means that the D50 value cannot exceed 60°.

In this set of experiments, polycarbonate formulations were prepared and evaluated in which various light diffusing agents were added at various concentrations to the preferred formulation of Table 5, i.e. both flame retardant A and C were used.

Table 3: **Series of experiments to investigate performance of flame retardants and effect of concentration levels**

Type of Primary FR Agent	A	B	C	D
PC type	CALIBRE 200-3	CALIBRE 200-3	CALIBRE 200-3	CALIBRE 200-3
V-0 at 1.0 mm	FAIL	FAIL	FAIL	FAIL
V-0 at 1.5 mm	PASS	FAIL	PASS	PASS
5VB at 2.5 mm	FAIL	FAIL	FAIL	FAIL
5VB at 3.0 mm	PASS	FAIL	PASS	PASS
5VA at 2.5 mm	FAIL	FAIL	FAIL	FAIL
5VA at 3.0 mm	PASS	FAIL	PASS	PASS
%T at 1.0 mm	90.3	90.4	90.7	88.2
%Haze at 1.0 mm	0.8	0.7	0.6	3.1

Table 4: **Series of experiments on flame retardant A and C**

Type of Primary FR Agent	A	A
Type of Secondary FR Agent	C	C
PC type	CALIBRE™ 200-3	CALIBRE™ 200-22
V-0 at 1.0 mm	PASS	FAIL
V-0 at 1.5 mm	PASS	FAIL
5VB at 2.5 mm	PASS	FAIL
5VB at 3.0 mm	PASS	FAIL
5VA at 2.5 mm	PASS	FAIL
5VA at 3.0 mm	PASS	FAIL
%T at 1.0 mm	90.2	90.6
%Haze at 1.0 mm	0.8	0.6

Figure 2:
Diffusion is evaluated by measuring relative transmittance (%)

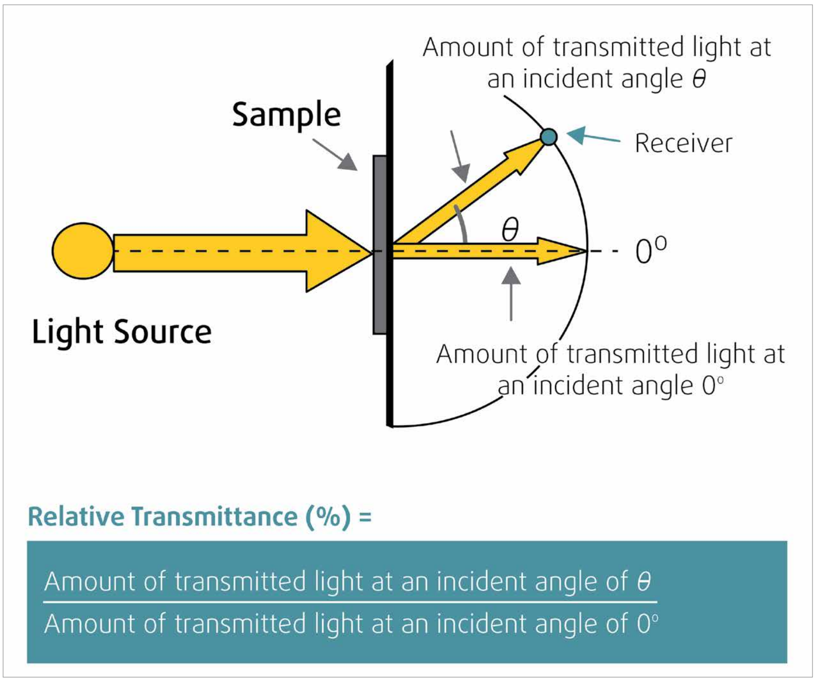


Table 5:
Series of experiments to measure flammability and light properties (optimized compositions)

Flame Retardant Package Type	A + C	A + C	A + C	A + C	A + C	A + C
CALIBRE™ PC Type	200-3	200-3	200-3	200-3	200-3	200-3
Light Diffusing Agent	E	E	F	F	G	G
Level of Diffusing Agent	LOW	HIGH	LOW	HIGH	LOW	HIGH
V-0 at 1.0 mm	PASS	PASS	PASS	PASS	PASS	PASS
V-0 at 1.5 mm	PASS	PASS	PASS	PASS	PASS	PASS
5VB at 2.5 mm	PASS	PASS	PASS	PASS	PASS	PASS
5VB at 3.0 mm	PASS	PASS	PASS	PASS	PASS	PASS
5VA at 2.5 mm	PASS	PASS	PASS	PASS	PASS	PASS
5VA at 3.0 mm	PASS	PASS	PASS	PASS	PASS	PASS
%T at 1.0 mm	75.6	58.0	74.0	54.50	67.63	55.86
%Haze at 1.0 mm	98.01	99.03	97.23	99.05	97.83	98.99
D50 at 2.0 mm	33.2	57.5	27.4	59.1	37.8	59.4

Table 6:
Series of experiments to measure flammability and light properties (not optimized compositions)

Flame Retardant Package Type	A + C	A + C	A + C	A + C
CALIBRE™ PC type	200-3	200-3	200-3	200-3
Light Diffusing Agent	H	H	I	I
Level of Diffusing Agent	LOW	HIGH	LOW	HIGH
V-0 at 1.0 mm	FAIL	FAIL	FAIL	FAIL
V-0 at 1.5 mm	FAIL	FAIL	FAIL	FAIL
5VB at 2.5 mm	FAIL	FAIL	FAIL	FAIL
5VB at 3.0 mm	FAIL	FAIL	FAIL	FAIL
5VA at 2.5 mm	FAIL	FAIL	FAIL	FAIL
5VA at 3.0 mm	FAIL	FAIL	FAIL	FAIL
%T at 1.0 mm	84.8	66.5	77.7	67.6
%Haze at 1.0 mm	96.54	98.88	95.97	98.50
D50 at 2.0 mm	2.0	46.1	19.8	55.6

Flammability and light properties, including D50, were measured on these materials. The D50 was measured on injection-molded plaques of 2 mm thickness. Results are reported in Tables 5 & 6.

The data from table 5 demonstrates that, using the optimized composition for the transparent flame retardant polycarbonate, light diffusing formulations can also be designed that offer excellent combinations of total light transmission and light diffusivity, as well as the desired and unique flammability performance.

To achieve that, the proper light diffusing technologies need to be selected, as demonstrated by the data in Table 6. Light diffusing compositions from Table 6 do not offer the same flammability performance and also have inferior light diffusing properties.

It is demonstrated that both transparent and light diffusing bromine-, chlorine- and phosphate-free, flame retardant polycarbonate compositions are designed offering a unique balance of flame retardancy and light properties (in terms of total light transmission and light diffusivity, if applicable). This is done by careful selection of the type of functional components in the formulation and their addition levels.

These developments have been the subject of a recently filed patent application and, in the meantime, have been UL certified, including f1 and RTI listings.

Meeting the Requirements Set by the Industry

There are many compositional parameters that impact the key functional requirements on flammability, transparency and haze that a material supplier needs to take into account. These effects have been elucidated through extensive testing, resulting in compositions meeting all key functional requirements that could be defined using extensive experimentation. As a result, R&D has designed a transparent flame-retardant composition including about 94% to about 98.9% weight polycarbonate, based on the total weight of the composition, and a sufficient amount of one or more flame retardants for the composition to meet the aforementioned requirements. This development has resulted in the launch of new and advanced resins that will serve as a technology platform for future grades of PC Compounds for the LED Lighting Industry.

Conclusion

A significant R&D effort is necessary to meet the current and future needs of the LED industry's leading and emerging companies. Manufacturers and designers are continuously looking at materials that offer a combination of properties which will allow them to produce thinner covers with excellent light transmission. Whether the goal is uniform light diffusion or crystal-clear transmission, outstanding ignition resistance (or flame retardancy) is a priority. The key is to master the critical performance triangle. In light of these new requirements, the new grade compositions meet the challenge of combining excellent optical properties, excellent flame retardancy and thinner lenses for the lighting system designer.

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Flame Retardants for Plastics and Textiles; Practical Applications; Edward D Weil and Sergei V Levchik;
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Development of a Workflow for Colored Ray Data

The importance of white LEDs has risen continuously over the past years. In many cases, disturbing color fringes appear on white LEDs with a blue chip and a yellow phosphor. To avoid this, different distribution of the blue and the yellow light has to be described for simulation. Therefore, colored ray files are necessary. Nicole Stubenrauch, Development Engineer at TechnoTeam Bildverarbeitung GmbH, explains a workflow and method for creating colored ray files.

Most light sources emit light of different wavelengths. For a light bulb the spectral power distribution is equal in each direction. This is not the case for many other light sources, for example, white LEDs with a blue chip and yellow phosphor. The different distribution of the light of different wavelengths has to be measured and used for simulation. In figure 1, different luminous intensity distributions (LID) are shown. The figures on the left and on the right show the distribution of the yellow (left) and the blue (right) light. In the middle, the differences are shown mapped onto the distribution of the yellow light. The differences are easy to see [1].

With colored ray data it is possible to develop a new product with fewer prototypes [5]. It is important to have the opportunity to simulate color fringes of the developed products. For creating colored ray data of white LEDs, a workflow has been devised.

Motivation

For simulating color fringes, ray files with spectral characteristics are necessary. Therefore, the light from the white LED has to be split into two ray-files: one ray-file with blue light directly from the chip and one with the phosphor converted yellow light.
To split the light into two colors suitable filters are important to sort the rays into the correctly colored ray-file.
For simulation both ray-files have to be combined with a spectrum that fits the rays that have been collected in it.
To create the blue and the yellow spectrum an integral spectrum has to be measured and divided into two parts. To get the right colors in the simulation, the two ray-files, combined with the spectra, have to be weighted in the simulation software because an agreement between measurement and simulation is very important. In most cases, the ray-file resulting from the workflow consists of the current data, with one wavelength per ray being added. So, all rays together represent the measured spectrum. It is also possible to combine each ray with the whole spectrum. In some software the use of color information is not possible yet. In 2011, Muschaweck described the different possibilities to integrate color information into the simulation software [4]. In the last years, much of the available software has changed, but nearly all programs still have different formats. So, there is a big amount of data to be generated and saved on the server for the LED manufacturer, as explained in [4]. In 2013, a new standard format [3] was published by the IESNA. In [6], it is described how the different formats could be used and integrated

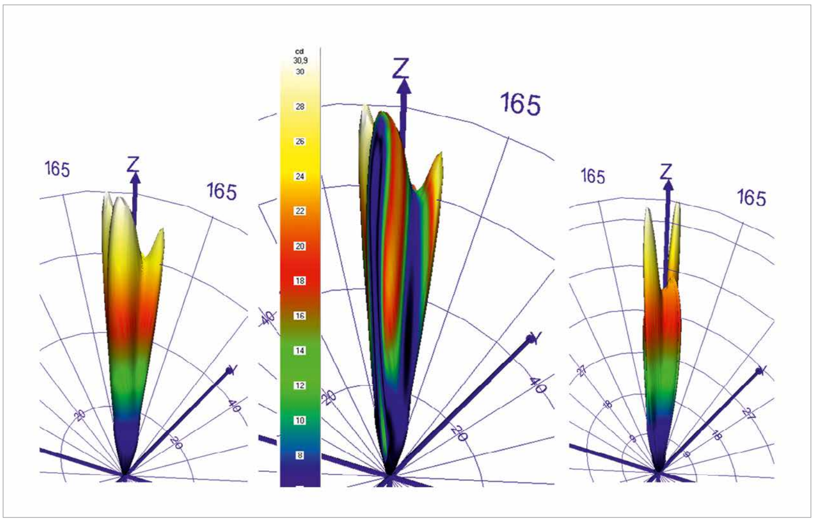

Figure 1: Luminous intensity distribution (LID) of a white LED (left: yellow light (LID), middle: comparison of yellow and blue, mapped onto the yellow LID, right: blue light (LID))

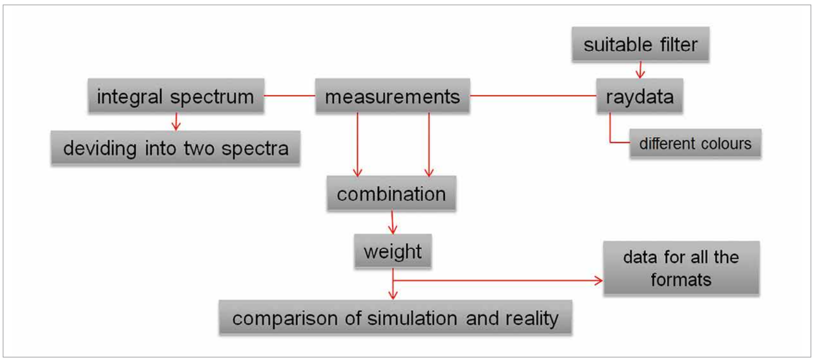

Figure 2: **Steps involved in the workflow**

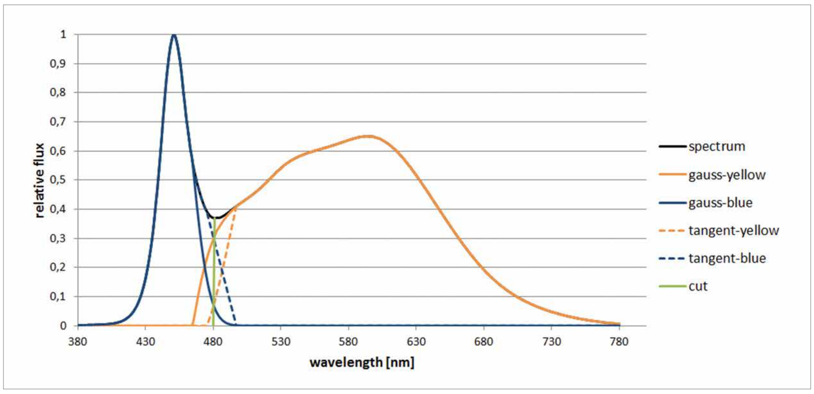

Figure 4: **A typical spectrum divided into two spectra. The two spectra are produced with a simple cut (green) or by approximation with a Gaussian distribution (straight line) or a tangent (broken line)**

in the software. Besides the method explained in this article, there are some further approaches described by Rykowski in [7]. He does not only use an integral spectrum, instead he measures the color at each point and determines the wavelength using an algorithm out of it. - The workflow is shown in figure 2.

Development of the Workflow

Integral spectrum

The first step in this workflow consists of the measurement of an integral spectrum. For this, a sphere or a goniophotometer equipped with a spectrometer can be used. For the present research work, the goniophotometer in figure 3 was used, as it is necessary also for measuring the luminous intensity distribution and the ray data. When measuring the spectrum at various points (e.g. $\Delta\Phi=90°$; $\Delta\theta=10°$), weighting with the appropriate solid angle an integral spectrum is calculated.

Figure 3: **Goniophotometer used in this investigation**

Separated spectra

To create two separated spectra out of the integral one a cut is necessary. Therefore, different possibilities were investigated. A simple cut at the local minimum between the blue and yellow spectral part is the easiest way. Also, functions can be used for an approximation at the curve. Investigations have shown that approximations with a Gaussian distribution or a tangent are comparable.

For the present research work, an integral spectrum has been created out of two single spectra. By dividing this into two spectra again using the algorithm, it can be shown how the different functions for the approximation fit the real spectra. Furthermore, the simulation results have been compared. In figure 4, an integral spectrum with different spectra resulting after dividing is shown. It can be said that all three kinds of separating a spectrum are possible: the cut at the local minimum, as well as the approximation with a Gaussian distribution or a tangent. These methods have been proved through simulation.

Two ray files

The spectra found need a ray file whose rays could be characterized by them. Therefore, it is necessary to measure two luminous intensity distributions, namely the blue and the yellow one. To sort the light into the two ray files, suitable filters have to be chosen. In the investigations for this workflow three kinds of filters were examined. They are shown in the following graph (Figure 5). Broadband filters for blue and yellow light (1 and 2), both filters for the X (lambda)-function (3 and 4), as well as interference filters (5 and 6). To decide which filters fit best, the percentage of rays measured by using the other respective filter is investigated, i.e., the portion of blue rays prevailing in the ray file is measured by using the filter for yellow light.

For different spectra the percentage of wrong rays amounts to 13% for filters 1 and 2, and to only 4% for filters 3 and 4. Furthermore, filters 3 and 4 are used very often because they are necessary for the measurement of the chromaticity coordinate. Finally, the interference filters were tested. They have to be chosen, with the spectra being well known. Consequently, they are not as easy to use as the other ones. On the other hand, the error because of wrongly sorted rays is very small. The use of these filters is sensitive to small changes to the setup.

Therefore, the use of filters 3 and 4 is advisable. They are easy to handle and suitable for all considered spectra. The error concerning wrong rays is small, and sensitivity is low. In addition, the filters are already available in most labs.

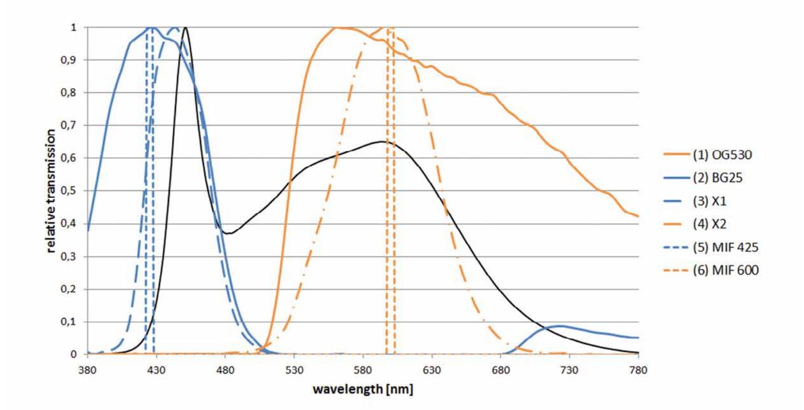

Figure 5: **Various characteristics of the filter developed**

Figure 6: **List of rays in a ray file with one wavelength per ray**

Informations

N	x	y	z	l	m	n	lambda	e
1	-3.468	1.763	9.212	0.098	0.082	0.992	465.722	1
2	-5.655	-1.114	8.172	-0.644	-0.089	0.760	429.588	1
3	0.286	-1.153	9.929	0.029	-0.064	0.998	438.565	1
4	0.814	-2.623	9.615	-0.041	-0.290	0.956	457.083	1
5	9.486	-1.045	2.987	0.990	-0.140	-0.034	447.680	1
6	1.370	-2.159	9.667	0.124	-0.142	0.982	443.025	1
7	-0.240	-2.552	9.666	0.043	-0.005	0.999	480.068	1
8	0.424	-1.042	9.936	0.006	-0.132	0.991	445.985	1

Data connection

After measuring the integral spectrum and dividing it into two parts as well as measuring the two ray data by using the filter chosen, they have to be combined. For this, tools are integrated in most of the simulation software or in the software of the measuring devices. A spectrum and a normal ray file can be put in there, and a ray file with one wavelength per ray will result.

Weighting

The next step is the weighting of both colored ray files to fit simulation and reality. To get the weights the proportion of the integral of the blue and the yellow part of the spectrum has to be calculated. This can be done for photometric and radiometric spectra. The relation has to be determined in luminous flux [lm] or radiant intensity [W] and integrated in the software or directly in the ray file.

Simulation

To create a useful simulation, it is necessary to know how the color is integrated. Different kinds of software present different principles of integration. In some software it is not possible to include color information. On the other hand, most kinds of software add one wavelength to each ray as can be seen in figure 6, whereas some other kinds allow a whole spectrum to be attached to each ray.

If each ray is assigned one wavelength all rays together represent the spectrum, but if only a few rays are picked up by the detector, the spectrum could greatly differ from the real spectrum, because the individual wavelengths are statistically distributed over the rays. Moreover, the time for simulation does not rise with integration of color. If the whole spectrum is integrated in each ray, the time for simulation is obviously longer, but also a small number of collected rays provide good results. So, both ways are acceptable, but the user has to know about the characteristics to interpret the simulation in the right way.

Conclusion

In conclusion it can be said that it is possible to create colored ray data for the simulation of white LEDs. Therefore, it is necessary to measure an integral spectrum and divide it into two spectra, a yellow and a blue one. For this, a simple separation through a cut at the local wavelength is accurate enough in most cases. Also, the ray data has to be measured using a filter that is suitable for both spectra. The smallest error and good handling is possible with both filters for the X (lambda)-function. The combination of spectra and ray data can be achieved by means of the software or by the manufacturer of the goniophotometer supplier. The weight has to be included relating to the integral of the two spectra.

This workflow has only been tested for white LEDs with a blue chip and a yellow phosphor; the application for other light sources has to be proven. In the future, it will also be possible to investigate other phosphors to close the gap between both parts of the spectrum. The separation into two spectra will be more complex then. At least one company [6] represents different color bins of LEDs through different weights of the two ray files in the simulation. In the framework of this investigation, however, this has not been tested and remains to be done in the future.

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Thermal Transient Testing of LEDs for More Reliable SSL Products

An LED device's reliability, useful operating lifetime and luminous flux are basically determined by the junction temperature; therefore, so is the lifetime and reliability of the final SSL application. Thermal transient testing is now supported by new industrial laboratory testing standards published by JEDEC. Dr. Andras Poppe, Mechanical Analysis Division, MicReD, at Mentor Graphics will explain the corner stones of this standard and discuss application examples. This includes measurement of the R_{thJC}, test-based thermal modeling of the LED package, hot lumens prediction, and monitoring of degradation of the thermal interfaces during life-time test, to name just a few.

An LED device's reliability, useful operating lifetime and luminous flux are basically determined by the junction temperature; therefore, so is the lifetime and reliability of the final SSL application (such as street lighting luminaires, cars' headlights, etc.). And this temperature is directly proportional to the total junction-to-ambient thermal resistance of the heat-flow path of the LED application.

Key contributors are the interfacial thermal resistance between the different sections of the heat-path such as thermal resistance of the die-attach, thermal resistances of solder/glue layers, and the thermal resistance of the TIM applied between the LED component and luminaire heat-sink (Figure 1). Thermal transient measurements completed with subsequent structure function analysis [1] has been proven to be a powerful means to test, monitor, and model these resistances during quality assurance, reliability testing, and thermal modeling for the design of system-level thermal management solutions.

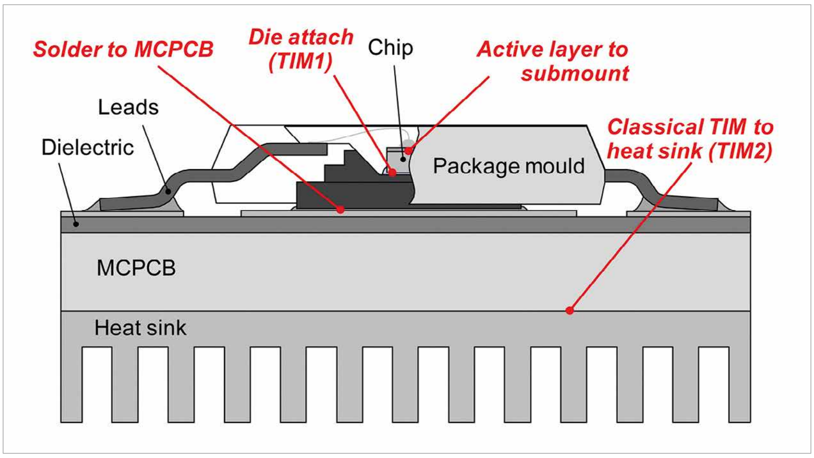


Figure 1: Thermal interfaces in the junction-to-ambient heat-flow path of a typical power LED application

In the case of power semiconductor devices packages and LEDs, the thermal transient testing is now supported by new industrial laboratory testing standards published by JEDEC, such as JEDEC standard JESD 51-14 aimed at the measurement of the R_{thJC} junction-to-case thermal resistance and the JEDEC JESD 51-5x series of standards aimed at the correct measurement of LEDs' real thermal resistance or thermal impedance with consideration of the emitted optical power (total radiant flux) of the device under test.

Given examples of the thermal transient testing for characterizing LED applications include measurement of the R_{thJC} combined with test-based thermal modeling of the LED package aimed at CFD based luminaire-level thermal simulations and hot lumens prediction, monitoring of degradation of the thermal interfaces during life-time test or reliability tests, and last but not least, the application of the thermal transient testing in qualifying the thermal quality of the die-attach layers.

Figure 2 presents the basic concept of thermal transient testing of LEDs. The test equipment forces a stepwise change in the heating power of the LED under test and measures the transient response of its junction temperature. Normalized by the

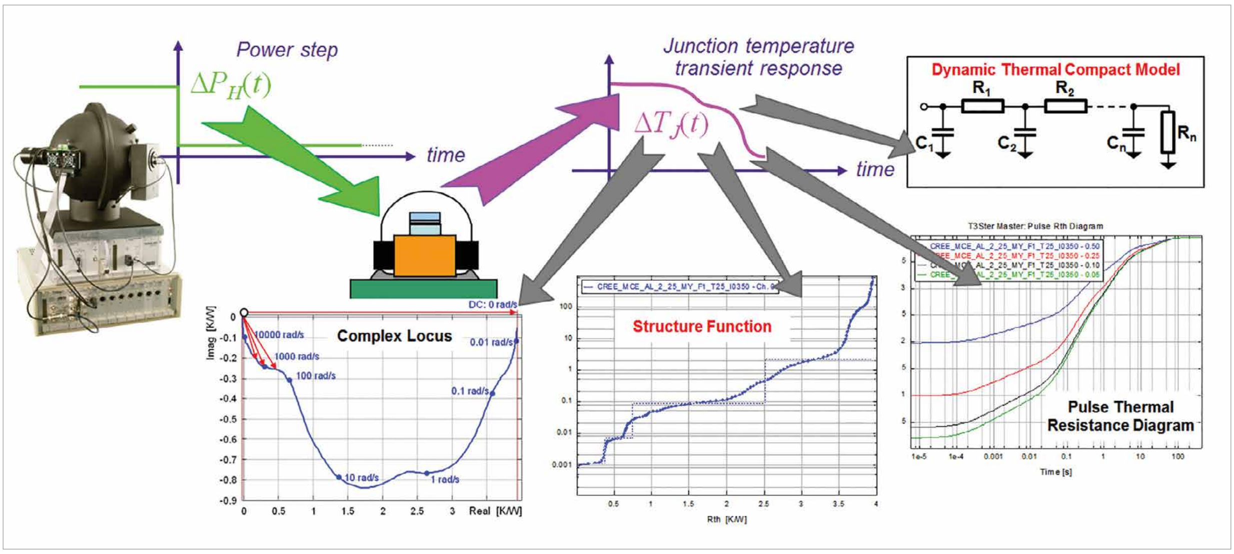


Figure 2: **Overview of thermal transient testing of LEDs: the junction temperature response to a stepwise change in the LED's heating power is measured and is post processed**

change in the heating power this curve is called the Zth(t) thermal impedance curve. After post processing, the thermal impedance is turned into alternate formats that can be used to represent the thermal behavior or thermal properties of the LED's junction-to-ambient heat-flow path for a particular purpose. For example, the complex locus is a format best suited to describe the thermal impedance of AC-driven LEDs; the pulsed thermal resistance diagrams are well suited to describe how LEDs would thermally react when dimmed with a pulse-width modulation; structure functions provide non-destructive means of failure analysis; and even a dynamic compact thermal model can be created to represent the LED package during a luminaire level CFD-based thermal simulation.

New JEDEC Standards Support Thermal Testing of LEDs

LEDs' operation extends to multiple domains: electrical, thermal, and optical, with rather strong mutual dependence among the major characteristic quantities such as forward current, forward voltage, total light output (e.g., total radiant flux), heat generated within the device, and the junction temperature (Figure 2). Therefore, testing of power LEDs, including thermal characterization, is not straightforward.

As measurement of light emission of LEDs and LED-based products is affected by the junction temperature, CIE (International Commission on Illumination) have also revised their recommendations on LED measurements and established several technical committees (such as CIE TC2-64, TC2-64 or TC2-76) that aim to define LED testing procedures with consideration of LED operating junction temperature. Thermal testing of LED components, or small LED assemblies, falls within the general category of thermal testing of packaged semiconductor devices – therefore the JC15 committee of JEDEC (Joint Electron Devices Engineering Council), dealing with thermal characterization of packaged semiconductor devices initiated a series of white papers on the need for LED thermal testing standards [2].

In the case of power semiconductor devices packages and LEDs, thermal transient testing is now supported by new industrial laboratory testing standards published by JEDEC, such as JEDEC standard JESD 51-14 [3] aimed at the measurement of the R_{thJC} junction-to-case thermal resistance [3], and the JEDEC JESD 51-5x series of standards [5-9] aimed at the correct measurement of LEDs' real thermal resistance or thermal impedance with consideration of the emitted optical power (total radiant flux) of the device under test. When the generic method of the JEDEC JESD 51-14 compliant measurement is combined with the JEDEC JESD 51-5x series of LED thermal testing standards, the real value of R_{thJC} junction-to-case thermal resistance can be obtained. In most of the LED packages, the assumption of a single heat-flow path from the LED's junction towards the cooling surface of the LED package (Figure 3) is valid.

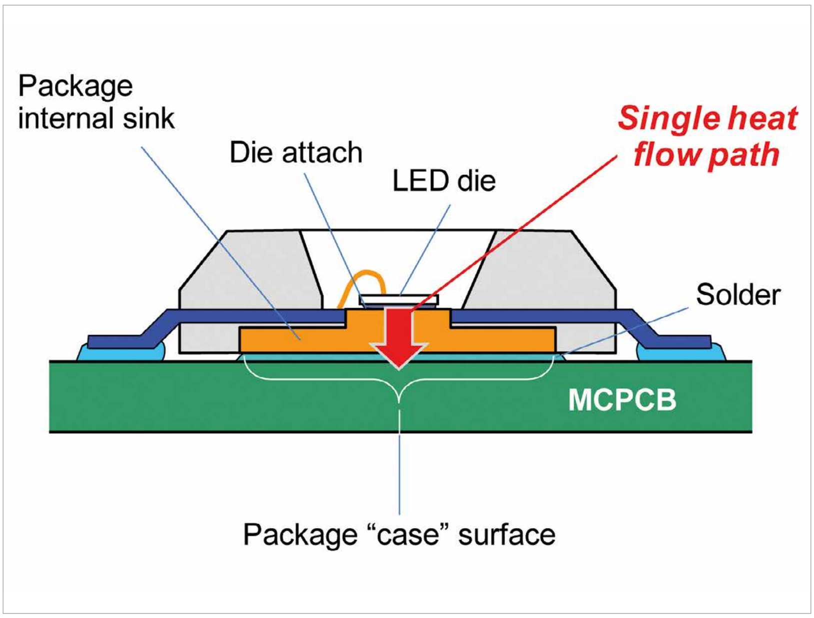


Figure 3: **A classical power LED package soldered to a metal core PCB substrate with its exposed cooling surface (the package 'case' surface)**

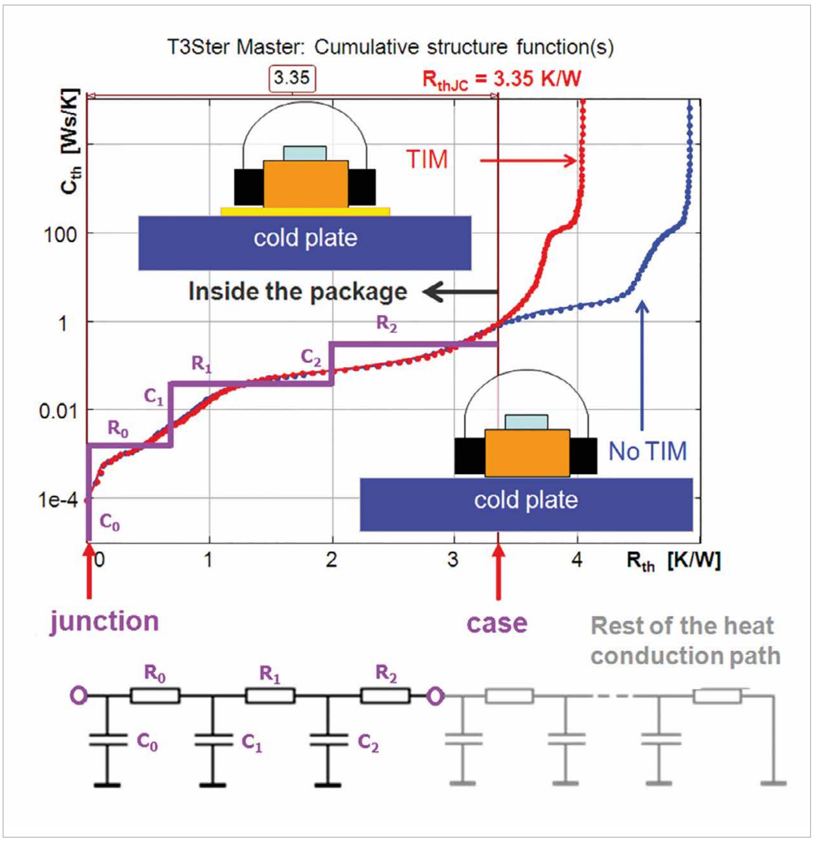


Figure 4: **Identification of the package R_{thJC} thermal resistance of a power LED device with the transient dual interface method of JESD 51-14 and the dynamic compact thermal modeling of the main heat-flow path of the package**

Measurement of the Real Thermal Resistance of LEDs and LED Assemblies

As mentioned before, measurement of the emitted optical power is important when calculating the LEDs' real thermal resistance (or thermal impedance if the dynamic thermal behavior is of interest). By neglecting the emitted optical power in this calculation, the resulting thermal resistance/impedance value would be smaller, and providing such thermal metrics on LED data sheets can easily mislead customers and may result in improper design of the thermal management of the final LED application. This was the main motivation of the JEDEC JC15 committee when the work toward the definition of LED thermal testing standards started in 2008.

Four documents (JESD 51-50 through 53) were created to be widely used in thermal characterization of packaged semiconductor devices and are specific to LEDs.

Transient Technique to Measure LEDs' Junction-to-Case Thermal Resistance

From a thermal point of view, packaged LEDs are similar to any other power semiconductor device for which the most important thermal metric is their junction-to-case thermal resistance. For the accurate and repeatable measurement of this metric, the JEDEC JC15 committee has developed a new JESD51-14 testing standard [3] based on the so-called transient dual interface method.

This method is characterized as follows: During the measurement, we assume that there is a single heat conduction path from the junction (location of heating) toward the ambient through an exposed cooling surface of the package. This surface is called the package 'case' (Figure 3). A further assumption is that such packages are designed to be heat-sunk during normal operation. In figure 3, the MCPCB substrate acts as a primary heat spreader and heat sink; and in a final application environment, it must be mounted to a cooling assembly.

Thus, during a JESD 51-14 compliant R_{thJC} measurement, the device under test has to be attached to a cold plate.

According to this standard, the junction temperature cooling transients of the device need to be recorded twice, using the JESD 51-1 electrical test method [10], with two different qualities of the thermal interface between the package 'case' surface and the cold plate. In one measurement, good thermal contact between the package 'case' and the cold plate need to be established (typically by applying any thermal interface material between the mating surfaces). This is also known as 'wet' condition because using simple silicon oil wetting the interface is sufficient. In the other measurement, bad thermal contact between the package and the test environment is needed; that is, no thermal interface material shall be used during this measurement. This condition is also known as 'dry' condition because no wetting material like silicon oil or thermal grease is used. In other words, once a thermal interface material (TIM) is applied, in the other case, no TIM is applied. Figure 4 shows test setup schematics.

The effect of the two different qualities of the 'case' – 'cold plate' thermal interface on the two measured thermal impedance curves – is that at a characteristic time the curves start diverging. The R_{th} value corresponding to this divergence point is the transient junction-to-case thermal resistance. The JESD 51-14 standard provides two methods to find the 'exact' value of the transient R_{thJC} value in a repeatable and reproducible way. One method is based on the difference between the structure functions (Figure 4).

Note: Structure functions are the thermal capacitance – thermal resistance maps of the junction-to-ambient heat-flow path; the shape of the structure function depends on the thermal properties and the geometry of the subsequent sections of the heat-flow path. For details on structure functions see the original paper of V. Székely or consult Annex A of the JESD 51-14 standard [3] or see Sections 4.4.4 and 4.4.5 of [11].

The JESD 51-14 standard provides definitions of the procedure used to find this separation point in a repeatable way. According to the standard, e.g., if the difference between the structure functions is greater than a pre-defined ε value, the divergence point is found. (The second method defined in the standard is based on the difference of the first derivatives of the measured thermal impedance curves – the divergence point and the corresponding R_{thJC} value is found in a similar way as in the case of the structure-function based method.) This separation point determines the value of R_{thJC}.

If the emitted optical power was considered in the calculation of the heating power of the LED during these tests (as the JESD 51-5x standards [5-9] require), the identified R_{thJC} value will be the real, physical value of the junction-to-case thermal resistance of the given LED package. This value is not only the major thermal characteristic of the LED package to be published on data sheets, but it can also be used in compact modeling of the LED component aimed at system level thermal simulations of LED based luminaires.

For details of different aspects of the JESD 51-14 compliant R_{thJC} measurements see the original papers by D. Schweitzer et al [12-16]. The first report about using this test method for the measurement of LEDs was published by S. Müller et al [17].

Test-Based Dynamic Compact Modeling of LED Packages

As suggested in the previous section, the junction-to-case thermal resistance of LED packages is also suitable for compact modeling of LED packages.

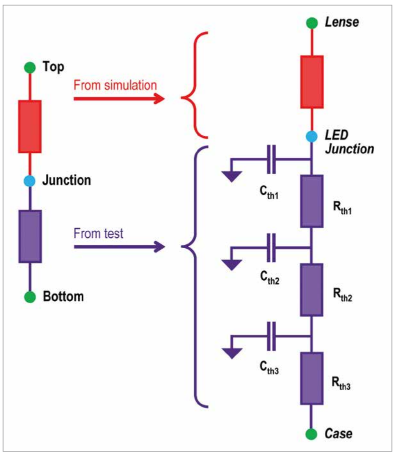


Figure 5: **The dynamic extension of the JEDEC 2R compact model for LED applications**

In principle, LED packages are well-modeled by a so-called JEDEC 2R model. In the case of LEDs, the two elements of this 2R model are the junction-case thermal resistance (corresponding to the junction-to-bottom resistance of the JEDEC 2R model) and the junction-to-lens thermal resistance (representing the junction-to-top part of the JEDEC 2R model) (Figure 5).

As described, measurement of the (real) R_{thJC} value of LED components is possible based on standards, but the identification of the junction-to-lens resistance raises problems: in practice it can hardly be measured. Because most of the heat dissipated at the LEDs' junctions leaves toward the cooling assembly of the LED packages, the junction-to-lens thermal resistance is large. Thus, as a first approximation, it can be neglected. However, if the need for accuracy in creating LED package compact models is required, this value can be determined by CFD simulation of the LED application.

There are situations when a steady-state compact model is not sufficient, such as for the AC-driven LEDs or the study of thermal effect of PWM-based dimming. In these cases, the dynamic extension of the JEDEC 2R model can be used (Figure 5). The element values of (thermal capacitance and thermal resistance values) can be obtained in a straightforward manner, e.g., by a step-wise approximation of the structure function up to the R_{thJC} value, representing the thermal impedance of the LED package.

Such an approximation is shown in figure 4. The sum of the thermal resistances of the model is equal to the R_{thJC} value. The model is independent of the applied boundary conditions at the case surface of the package, so such a model can be considered as a BCI (boundary condition independent) compact model. A complete dynamic LED package compact thermal model is shown in the right hand side of figure 5. Like the classical JEDEC 2R model, this dynamic extension of the JEDEC 2R model is also a test-based compact model.

The step-wise approximation of the structure function (Figure 4) is a natural extension of the data processing part of the JEDEC JESD 51-14 compliant transient R_{thJC} measurement method as implemented the T3Ster® Master data processing software which is also equipped with an interface which propagates such test based dynamic compact models towards CFD-based thermal simulation tools.

When the thermal transient measurement is combined with radiometric/photometric measurements of LEDs, JEDEC JESD 51-51/51-52 compliant measurement of LEDs' properties is possible. Synchronized with the powering of the LED under test, the integrating sphere based radiometric/photometric test setup provides the light output characteristics of the LED under test. By sweeping the temperature of its temperature-controlled LED fixture, parameters of a multi-domain LED model (including temperature dependence of the luminous flux) can be automatically identified. The workflow is shown in figure 6.

CFD simulation tools are typically used in the design of complete LED luminaries. Application of compact thermal models of (LED) packages allows speeding up the CFD simulation so that different design scenarios of LED luminaires can be analyzed and LED junction temperatures accurately calculated.

As during the JEDEC JESD51-51 tests used to obtain the thermal impedance curves for the identification of the real R_{thJC} values of LED packages and the light output properties are also measured, it is possible to measure the junction temperature dependence of these properties as well.

Besides the total radiant flux (needed for the thermal measurements), the same measuring setup can also deliver the total luminous flux, also as function of junction temperature, thus, the temperature sensitivity of the luminous flux can be easily identified for a constant DC current driven LED. In the simplest case, this temperature dependence can be approximated by

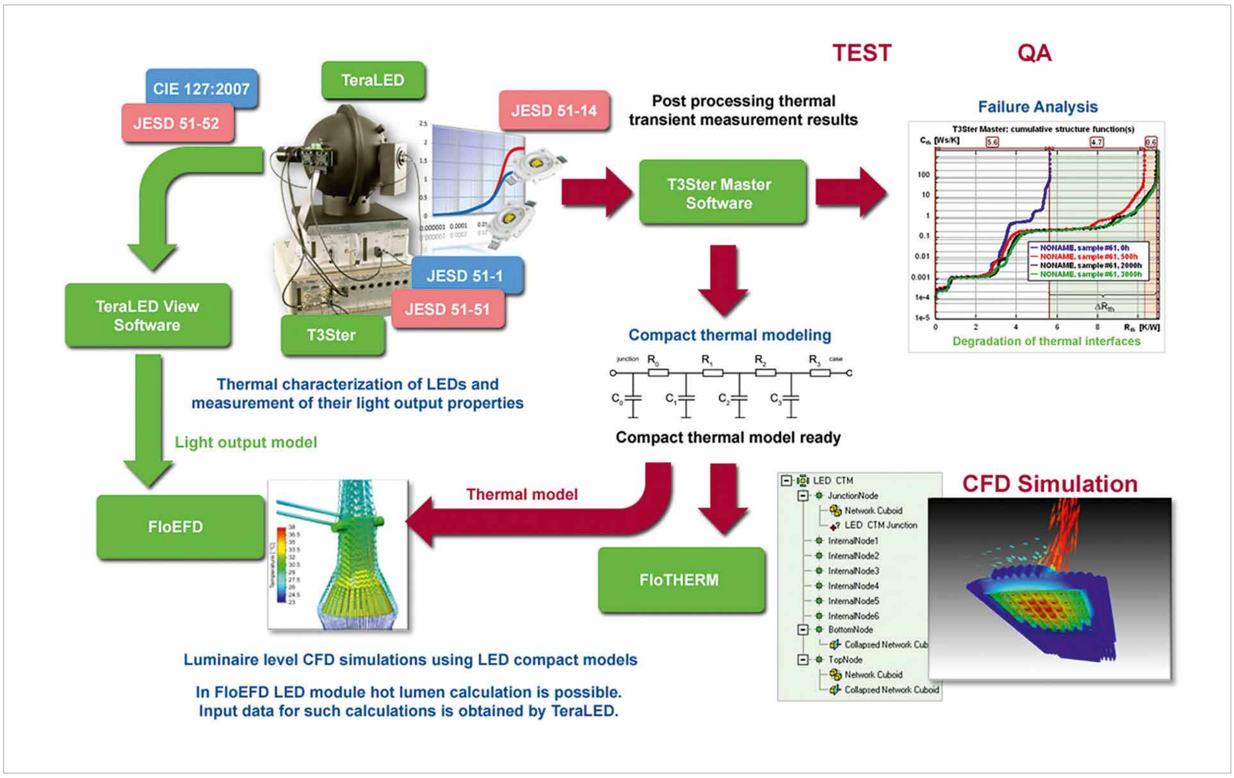


Figure 6: **Typical workflow for component level measurement, modeling, and luminaire level CFD simulation**

a linear relationship allowing hot lumen predictions of LEDs as part of the CFD analysis of an LED luminaire.

The equations used in the multi-domain LED model implemented in the FloEFD tool are the following:

$$V_F(I_{F0},T_J) = V_{F0} + S_{VF0} \cdot (T_J - T_0) \quad (1)$$

$$\Phi_e(I_{F0},T_J) = \Phi_{e0} + S_{\Phi e0} \cdot (T_J - T_0) \quad (2)$$

$$\Phi_V(I_{F0},T_J) = \Phi_{VV0} + S_{\Phi V0} \cdot (T_J - T_0) \quad (3)$$

where V_{F0}, Φ_{e0} and Φ_{V0} are reference values of the forward voltage, radiant flux (emitted optical power) and luminous flux, respectively (measured at the T_0 reference temperature of the LED's junction) and S_{VF0}, $S_{\Phi e0}$ and $S_{\Phi V0}$ describe the temperature dependence of the quantities.

Equations (1) and (2) are used during the CFD simulation to update an LED's heating power and equation (3) is used to calculate the hot lumens of an LED for the T_J junction temperature obtained by the CFD simulation.

Luminaire-level CFD simulations are especially useful in the case of LED-based luminaires with very complex geometry where measurements on actual product prototypes under different conditions is difficult. In applications where luminous output is critical even under harsh environmental conditions, such as automotive luminaire, the hot lumen calculation realized within a CAD based CFD tool is crucial (Figure 7).

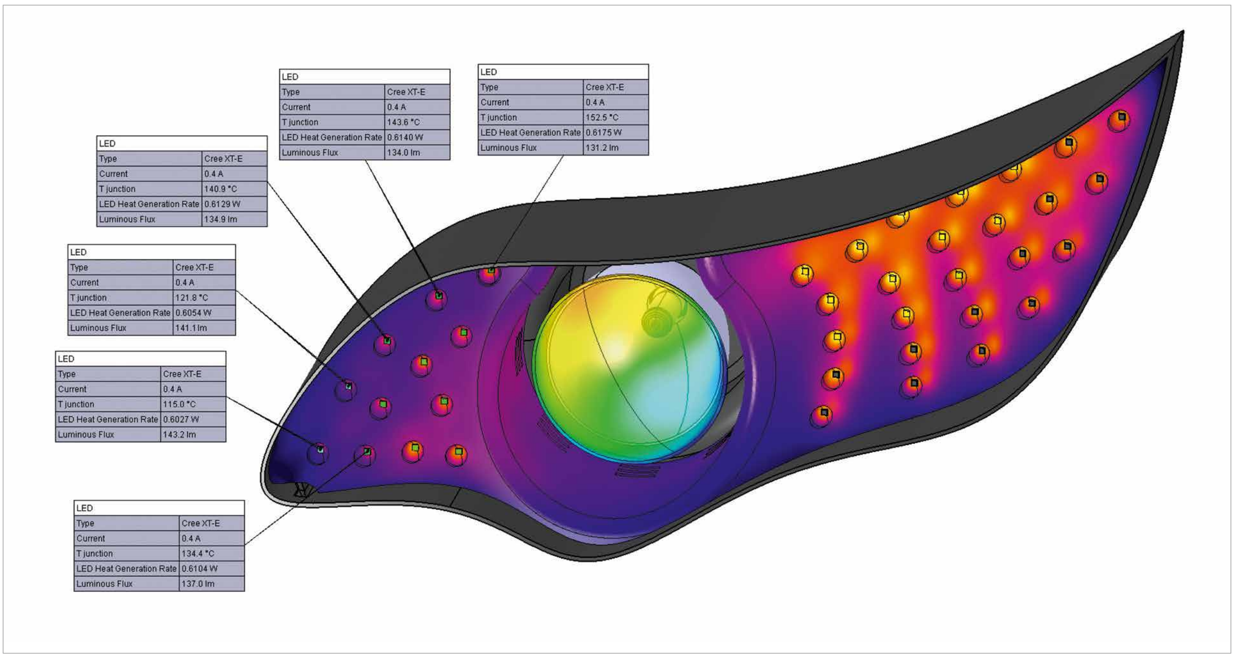


Figure 7: **CFD simulation results of a headlight luminaire completed with LEDs for running daylight using the CAD model of the luminaire as input for the CFD simulation. Results include temperature map and calculated hot lumens of each LED of the luminaire**

Example of Thermal Transient Testing in Failure Analysis of LEDs

In an independent series of tests carried out by the joint team of the University of Pannonia (Veszprém, Hungary) and the Budapest University of Technology and Economics (Budapest, Hungary), it was shown that the light output degradation of LEDs measured during LM-80 compliant aging is strongly correlated with degradation of the quality of the junction-to-ambient heat-flow path of the LED product tested [18] (Figure 8). The observed changes included delamination of the attachment of the LED package to the substrate (MCPCB in this case), as well as degradation of the thermal conductivity of the thermal interface material used in the test setup. The corresponding increases in the interfacial thermal resistances are indicated by the elongation of flat regions of structure functions.

As Figure 8 shows, the delamination of the attachment layer occurred within 500 h of aging time (see the differences between the 0 h and 500 h plots). TIM aging occurred between 500 h and 2,000 h of aging time. After 2,000 h of aging, no further degradation of the quality of the junction-to-ambient heat-flow path was observed.

In this LM-80 compliant aging test of LEDs, thermal transient measurements proved to be an effective means of post-stress failure analysis tools. The idea that thermal transient measurement of LEDs is a good means of pre-stress and post-stress test in reliability analysis is exploited recently in the EU funded research project NANOTHERM [19]: a thermal reliability testing system is being developed in the project in which thermal transient testing will be used as pre- and post-stress analysis technique. This concept applied to LEDs has been recently published [20].

In another example, die-attach quality issues were detected. The diagrams in figure 9 show the results of thermal transient testing of 15 randomly selected samples of a recent high-end power LED purchased from a distributor of a well-recognized LED vendor.

In figure 9a, the measured thermal impedance, for two samples out of the lot of 15, is already significantly higher 10 min. after turning the power on. This time range is characteristic to the die-attach region. The conclusion that the increased overall steady-state thermal resistance of these two samples was caused by the increased die-attach thermal resistance is confirmed as the structure function shown in figure 9b.

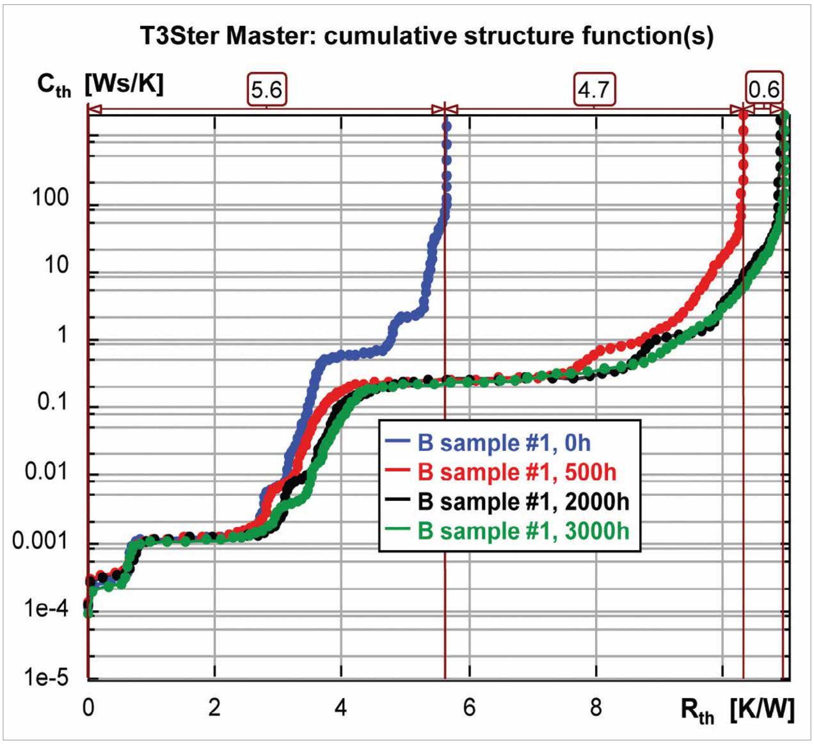


Figure 8: **Thermal interface degradation indicated by structure functions during an LM-80 life-time test experiment [18] (image courtesy the Budapest University of Technology and Economics)**

The fact that die-attach issues have been found in about 13% of the LEDs purchased through usual commercial channels highlights the importance of testing the die-attach quality during production.

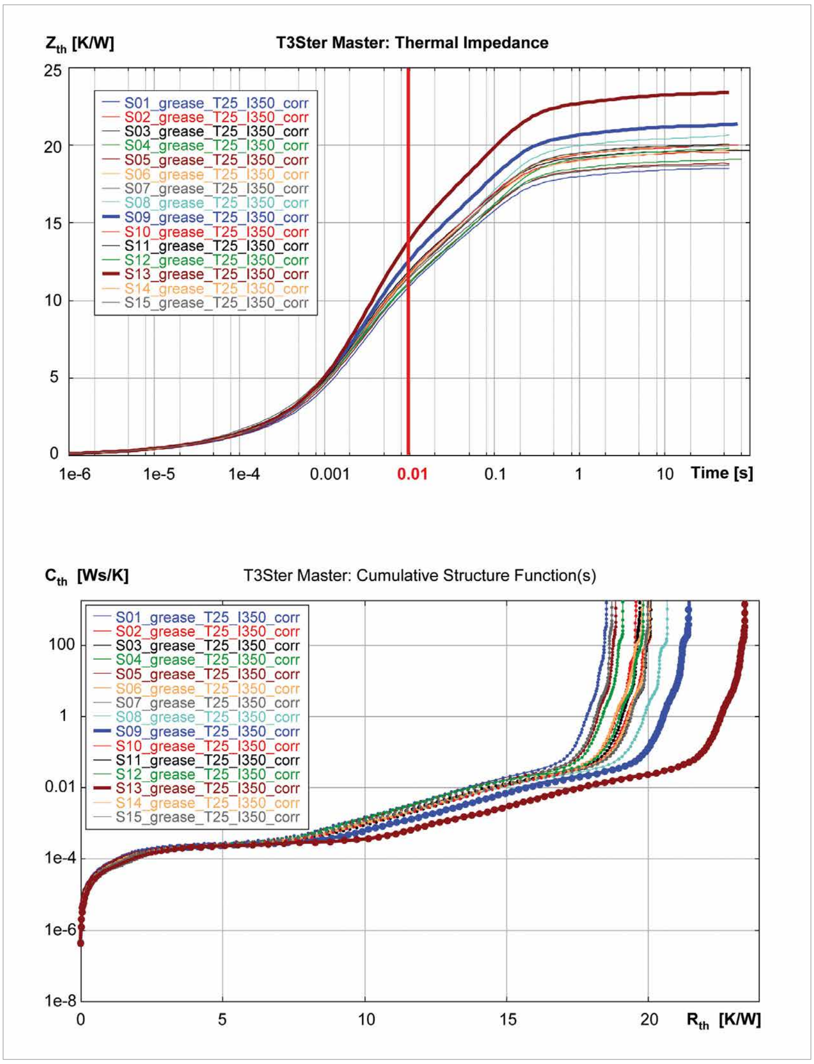
Such in-line testing of die-attach quality LEDs raises a number of questions:

First of all, to meet the speed requirements of the production lines, complete steady-state to steady-state thermal transient measurements are not feasible. In our earlier studies [21, 22], it was shown that transient response to short (typically 10 min.) heating pulses already carry the necessary information about the die-attach quality; thus, test waveforms with an overall length of 80 to 200 min. are appropriate, depending on the actual thermal time-constant of the LED product to be tested. Such a time frame corresponds to the throughput of production lines.

Another important issue is that during in-line testing of LEDs, there is no possibility to find the temperature sensitivity of the forward voltage of the LEDs, as would be required by the standard laboratory testing of thermal properties.

This problem can be solved by matching the initial part of the measured $\Delta V_F(t)$ transients to the real $Z_{th}(t)$ curves in the initial section (in the 1..10 min. range) where the heat-wave generated by the short heating pulse propagated only in the LED chip itself and is not yet influenced by the quality of the die attach. A recent paper by T. Dannerbauer and T. Zahner [23] provides details on this. The key in such a testing solution is the accurate measurement of the early part of the forward voltage transient.

Figure 9:
Thermal transient measurement results of 15 randomly selected commercial samples of recent SMD packaged high power white LEDs:
a) Measured thermal impedances,
b) corresponding structure functions.
The results for the two samples showing increased die attach thermal resistance are shown with thick lines



Conclusions

Thermal transient testing of LEDs is a powerful tool in thermal characterization of LED products in different phases of design and production.

Classical laboratory measurements of LEDs based on thermal transient testing can deliver accurate and repeatable results for the real junction-to-case thermal resistance of LED packages. A small addition to the data processing of the JEDEC JESD 51-14 compliant measurement of the junction-to-case thermal resistance measurements results in test based dynamic compact thermal models, which allows fast system CFD simulations of LED-based lighting solutions.

The other major application of thermal transient measurements of LEDs is in the reliability testing and quality assurance of LEDs. Used as a pre- and post-stress testing method, such measurements provide a good means of failure analysis. When implemented in production lines, thermal transient testing can be used for die-attach quality testing. All these applications contribute to the design and manufacturing of more reliable LED-based products. ■

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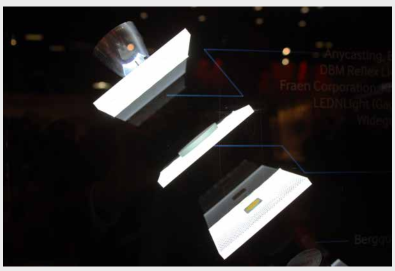

LED system scheme at the Samsung booth at the LED professional Symposium +Expo 2014 in Bregenz

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Costs & Processes
Issue 47 - Jan/Feb 2015 -
Short Overview

Year of Light Special:
2015 - Year of LED Light

The inventors of the blue & white LED were honored with the Nobel Prize in Physics on October 7th 2014. LED technology is undoubtedly the biggest revolution in lighting since the light bulb, creating new opportunities and challenges. The article will discuss the impact of light on humans, main considerations for lighting and future technical developments and trends. ■

Light Source Technologies to Satisfy Demands and Challenges of Modern and Future Lighting Applications

LED technology is changing the way light can be delivered to users. While LED lighting is reaching maturity, the application defines the technical development more and more. Different technologies, especially OLED, light-guide technologies and flexible light tiles will be compared, the opportunities and limitations discussed. ■

Technical Challenges of Advanced, Future Lighting Products for Module Manufacturers

Today's biggest challenge lies in the design of the LED lamp. In the future, in addition to pure "energy saving", light control, the Internet of things, photo biological effects and therapeutic options will play an increasingly important role. This article will discuss what this means to a module manufacturer. ■

Certification:
How to Communicate on the Quality of LED Luminaires

Specifying LED Luminaires seems to cause many misunderstandings between manufacturers and end-users or specifiers. Adhering to a standard and adding a quality label is not the solution that the industry is looking for. In order to avoid misunderstandings a new setup and certification system, built around this set of parameters, were created. ■

Electronics:
Progress in Driverless LED Light Engines

So called AC LED light engines tend to have a good power factor but poor flicker content. This article presents a new generation that has continuous DC output current through the LEDs with only a low ripple at 240/200 Hz, a typical 24% THD and a power factor of 0.45. Ongoing work to improve the power factor will also be described. ■

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