LED professional Review

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ISSN 1993-890X

LpR

The Global Information Hu... Technologi... Design

May/June 2021 | Issue 85

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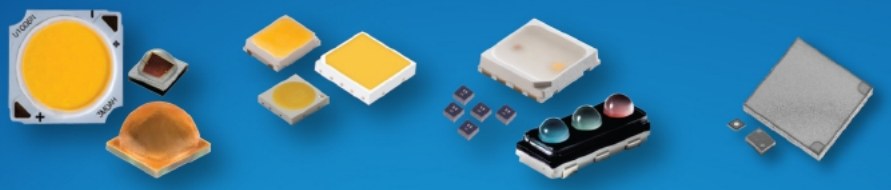
CREE LED



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Core Trends in Lighting

LpR, issue#85 is being published close to UNESCO's International Day of Light that officially takes place on May 16th every year. This is the ideal day to ask ourselves where we are going in the field of light. In this sense, we are grateful to John Dudley, Steering Committee Chair, who has written the commentary on page 8. The articles in this issue also take a look at future developments. Here are some examples:

Human Centric Lighting: The research on intrinsically photosensitive retinal ganglion cells in the human eye have initiated many new impulses, from lighting specifications to new spectrally optimized components to new application solutions. You'll find several articles presenting backgrounds and answers in this area (pg. 22, pg. 30, pg. 42). Since this field is still relatively new, we can expect to see many further studies and practical utilizations. There is also the LpS Digital lecture by Prof. Lucas about Lighting & Biology on page 20.

Innovative Light Sources: The further development of light sources doesn't stop. LED sources, specifically tuned to usage, are continuously being developed further (pg.42). Laser light is entering the markets as well (pg. 56).

Wireless Communication: The shift towards wireless communication in the lighting sector is also evident, whether employing Bluetooth solutions or the DALI+ or Wireless DALI Gateways presented in this issue (pg. 48 and pg. 52). Wireless is also developing more and more into IP-based architectures, as has been the case for many years already.

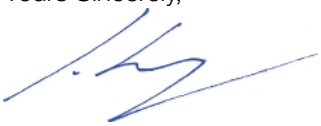
Circular Economy: Circular Economy will remain a key topic – it's clear that we need it. Our interview with Mark Ridler also shows how lighting designers and project owners see Circular Economy. His thoughts can be beneficial for getting a broader understanding of it. They may also help us to join forces in this matter.

Do you see other impacts? Write to us and let us know.

Finally, I would like to express my sincere thanks to all our contributors.

Enjoy your read and stay healthy!

Yours Sincerely,



Siegfried Luger

Luger Research e.U., Founder & CEO
LED professional, Trends in Lighting, LpS Digital & Global Lighting Directory
Photonics21, Member of the Board of Stakeholders
International Solid-State Lighting Alliance (ISA), Member of the Board of Advisors
Member of the Good Light Group and the European Photonics Industry Consortium

The **Most Efficient** and **Reliable LED** solution for **Outdoor**

Z5M4

A new High Power Technology

Developed by Seoul Semiconductor this LED package i**ncorporates the latest chip technology** of Seoul Semiconductor called **WICOP,** a monolithic chip that overcomes all lateral and other vertical chips created until today with the greatest efficiency

No Changes for Great Benefits

With a **standard platform** compatible with the old platforms **3.5 x 3.5** mm LEDs. This package is capable to deliver more than **345 lumens at 175 lm/W @85C** with a very strong reliability design and a great **compatibility with existing lenses** already available in the market.

Need to support **hot and cold extreme temperatures**? Need for a **long lifetime** ? Need to be **price** competitive ? Need for **Top Efficacy** High Power LED ?

No Problem. **Z5M4 is your NEW solution.**

Key Features of Z5M4

1. TOP Efficacy

175 lm/W
345 lm
Tj 85C 700mA

2. Most Reliable LED

Based on **WICOP** chip
No Wire bonding
Sulphur protected
Superior Thermal Performance

3. Long Lifetime LED

L90 > 100Khours @85C

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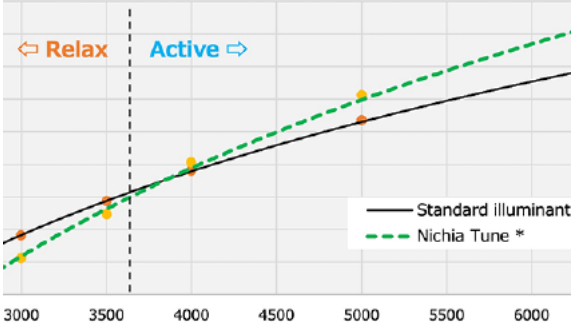
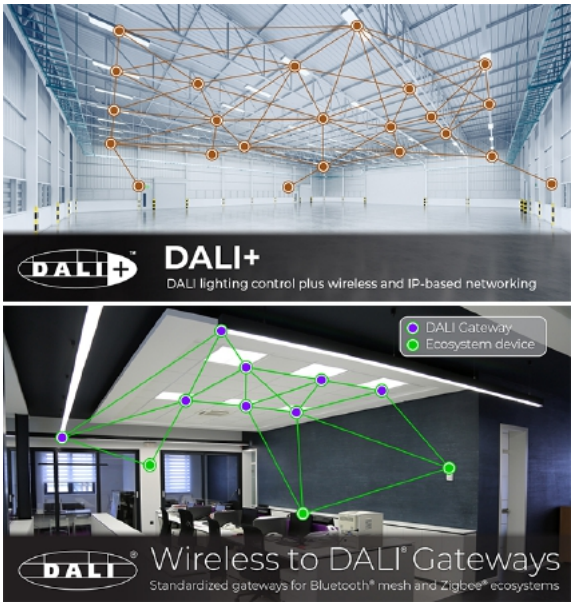
John DUDLEY speaking at UNESCO during 2015

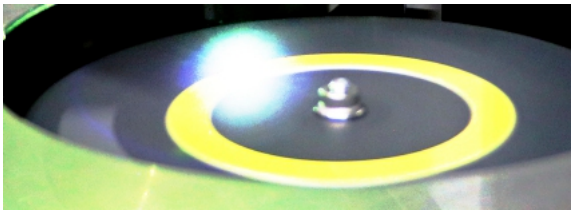


DALI+ AND WIRELESS TO DALI GATEWAYS

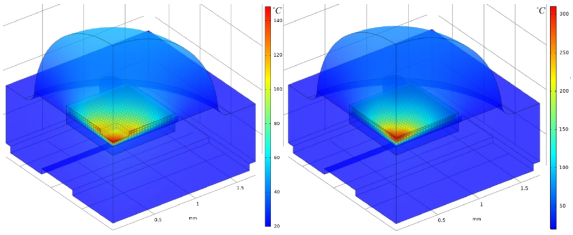


WIRELESS CONTROL NETWORKS

LASER LIGHTING TECHNOLOGY



THERMAL RESEARCH



ADVERTISING INDEX

Science in the Spotlight for the International Day of Light 2021

Prof. John DUDLEY

John DUDLEY is Distinguished Professor of Physics at the Université de Franche-Comté and the CNRS Research Institute FEMTO-ST in Besancon, France.

His research spans a period of more than 30 years in which he has contributed to optical source development, ultrafast and nonlinear fibre optics, and the interdisciplinary physics of nonlinear waves. He has won a number of national and international awards, including the Harold E. Edgerton Award for High-Speed Optics of SPIE and the R.W. Wood Prize of OSA. He is a Fellow of IEEE, IOP, EOS, SPIE and OSA, and an Honorary Fellow of the Royal Society of New Zealand Te Aparangi.

He initiated the International Year of Light and Light-based Technologies in 2015, and currently chairs the International Day of Light Steering Committee.

Now in its fourth year, the UNESCO International Day of Light is one of the most anticipated science events on the global calendar of United Nations observances. Since its inception in 2018, over 1200 activities and events of all kinds have taken place in more than 80 countries, and even aboard the International Space Station!

The overall objective of the International Day of Light is to raise awareness of how light impacts society, uniting scientists, engineers, educators, and industry practitioners from a wide range of different fields. The International Day of Light encompasses all areas where light affects our lives – basic science, lighting, art, culture, and sustainability. A focus of the International Day of Light has always been the development of new and energy-efficient lighting technologies, and working with UNESCO reminds us that many of the most urgent lighting needs are in developing countries.

Of course, even while we look forward to celebrations during 2021, we cannot forget the global circumstances of the COVID pandemic that continue to be challenging in many ways. Yet the events of the last 14 months have highlighted just how central light-based technology is to modern society, and how it has provided the solutions to the many problems we have faced. For example, the internet and video-conferencing have enabled continuity in industry and education even while so many have been confined to their homes, and the science of light has been key to developing responses to the pandemic in areas such as research, diagnostic medical tools, and UV sterilization.

Even more significantly, we have come to appreciate the importance of facts supported by scientific research, and we have been reminded how much we rely on dedicated professionals — in fields from healthcare to engineering — to find evidence-based solutions to society's challenges. And yet we have also seen how a simple and seemingly-obvious message of trusting the advice of scientists can become politicized and lead to confusion with tragic consequences. As a result, a key action of the International Day of Light in 2021 is the launch of a dedicated campaign to promote societal awareness of the need to "Trust Science." Supported by Nobel Laureates, science and industry leaders, and educators worldwide, the campaign aims to reach out to the general public and to invite them to make a simple yet very important declaration of confidence in the scientific process. The pledge takes less than a minute and can be easily completed online at www.trust-science.org

"The International Day of Light encompasses all areas where light affects our lives – basic science, lighting, art, culture, and sustainability."

PROFESSOR JOHN DUDLEY, CHAIR OF THE INTERNATIONAL DAY OF LIGHT STEERING COMMITTEE

The International Day of Light is only the start of the Trust Science campaign, and this message will be a focal point of many other outreach and education activities throughout 2021. Our hope is that the International Day of Light community will help this important message to reach a truly global audience. In this context, it is worth stressing here that the success of the International Day of Light has only been possible because of the tremendous grass-roots enthusiasm of all those who are passionate about light and its many benefits for society. This enthusiasm grows with every year, and we are confident that 2021 will see another fantastic celebration to light up the world. ■

J.D.

The universe created the sun. All other lights can be created with PLEXIGLAS®.

The great thing about PLEXIGLAS® is that it is always in impressive shape – to be specific, in precisely the shape you require. That's because our high-performance plastic can be individually formed, making it possible to create entirely new lighting concepts. PLEXIGLAS® also outshines conventional materials in terms of transparency and durability. Get to grips with PLEXIGLAS® and find inspiration by visiting **www.plexiglas-polymers.com.**

PLEXIGLAS®

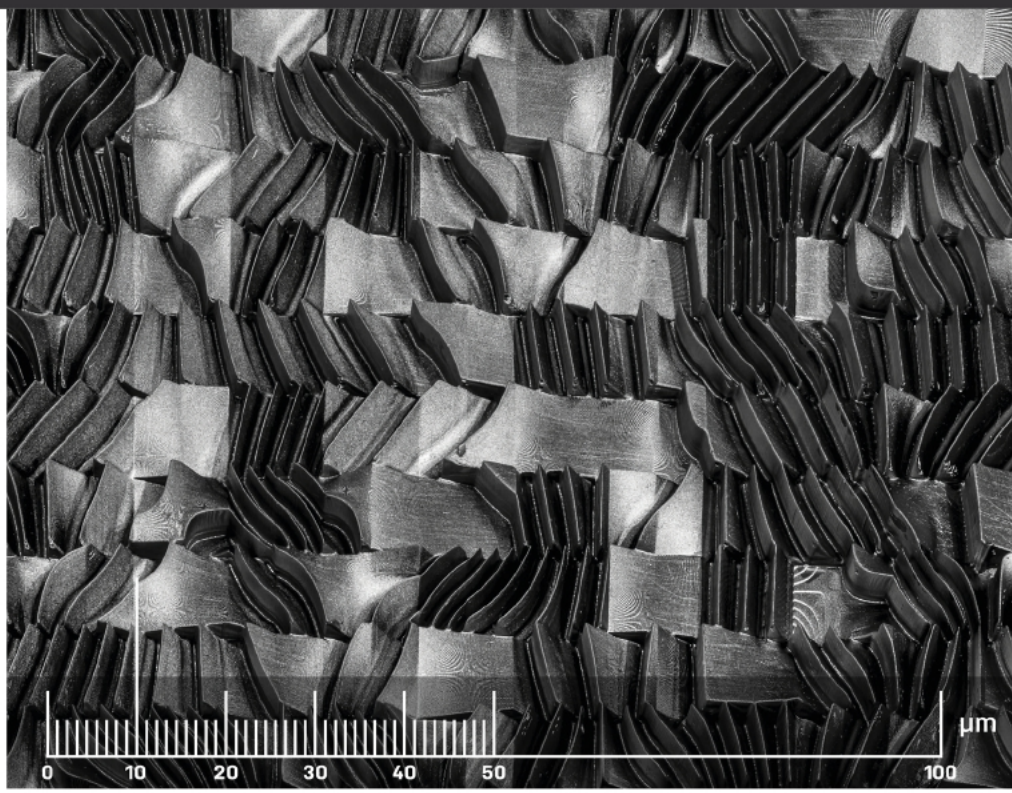
THE ORIGINAL BY RÖHM

RÖHM

NANOTTICA

ABSOLUTE LIGHT CONTROL WITH NANOTTICA

More than three years ago, the company TREVOS, a.s. discovered an opportunity that would break existing technical standards in the way light beams are distributed. The result of our three years of intensive development is the NANOTTICA luminaire with patented production technology.



WORLD INNOVATION

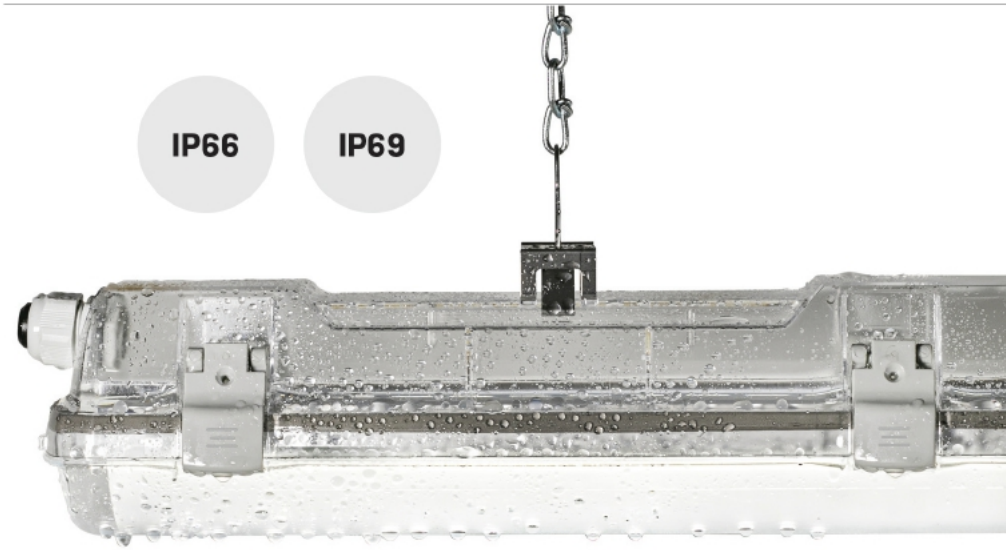
This high-end worldwide unique production technique equips our transparent luminaire cover with an embossed **nanooptical structure**. The nanooptical structure allows for more precise light distribution whilst maintaining high level performance across all other fundamental factors.

FULLY CONTROLLED LIGHT BEAM DISTRIBUTION

As **the first company in the world**, we are introducing an optical system for luminaires based on a huge number (millions) of tiny nanostructured surfaces. By precisely adjusting the parameters of such optical units, located on the inner surface of the transparent luminaire cover, we can achieve new unique optical functions. Our **breakthrough optical system** allows the combination of several features into a single optical element that would otherwise be implemented by a multi-element system, thus ensuring perfect visual manifestation of the luminaire in its on and off state. Thanks to the extremely high resolution, we can assign a unique function to each **nanostructured** surface and precisely control its light emission into the entire space. This successfully eliminates the high level of brightness the LED chips produce while maintaining high efficiency (above 90%) of the entire system. Thus, producing thorough control of the discomfort glare index, UGR 19-25, which is the result of a **fully controlled light beam distribution**.

HIGH VISUAL PERFORMANCE

NANOTTICA is designed for common industrial spaces in the first place, but with its unique optical properties it also meets the requirements for more demanding environments. It ensures the necessary **visual comfort** and high **visual performance** needed for improved work **safety**. Indirectly, these improvements contribute to higher levels of **productivity**. We recommend the use of NANOTTICA in applications such as, precise craftsmanship, visual inspection for, grinding shops, paint shops, factories, warehouses etc.



RADIATION CHARACTERISTICS FLEXIBILITY

NANOTTICA builds on our most successful line of PRIMA LED luminaires and offers a choice of three radiation characteristics (basic, wide-emitter and narrow-emitter), which are optimized for medium, low and high spaces. Thanks to our unique production technology developed by TREVOS a.s., we can flexibly expand the range with other types of radiation characteristics.

TECHNICAL PARAMETERS

The luminaire is available in **three lengths** following the original fluorescent variants, i.e. 600, 1200 and 1500mm. We offer a wide range of modifiable variants based on the basic version. Other equipment can be 1F or 3F internal throughwiring, HF sensors, 1h and 3h emergency modules, DALI drivers, CASAMBI control, etc. In the basic version, the luminaire is suitable for environments with ambient temperatures up to **+50°C**. Thanks to the **multifunctional ceiling clips**, the luminaire can be easily attached to a 60mm wide track lighting system.

Furthermore, thanks to the variable space between the clips, the old luminaires can be replaced by the new ones on the existing suspension structure of the original lighting. It reduces not only the labor cost but also the cost of the new suspension structure.

NANOTTICA has both **IP66 / IP69 protection**. It is offered in two material versions, PC and ABS, with a wide range of applications in environments that may have various chemicals and hazardous conditions. The robust construction of the luminaire ensures a high mechanical resistance of **IK10** whilst adhering to internationally recognized certifications **ENEC, CB, DLG, HACCP** expected by our industry.

BUSINESS

LightingEurope Board and President Elected

On 26 March the General Assembly elected a new Executive Board for a 2-year mandate. The Executive Board consists of an equal number of representatives of national lighting associations and corporate members of LightingEurope and has the role of implementing the LightingEurope strategy and work plans.

Lionel Brunet

On the same day the Board re-elected Lionel Brunet as President of LightingEurope, for a second term of 2 years. Mr. Brunet has been the CEO of the French lighting trade association "Syndicat de l'Éclairage" since 2013, and previously had a long international career in the chemicals and mechanical industries, and a global trade association.

The Executive Board consists of the following members (in alphabetical order of family name):

- Katia Valerie Banoun, Lyskultur, Norway
- Alfredo Berges, ANFALUM, Spain
- Lionel Brunet, Syndicat de l'Éclairage, France
- Nathalie Coursière, IGNES, France
- Massimiliano Guzzini, ASSIL, Italy
- Frank Hohn, OSRAM, Germany
- Peter Hunt, LIA, UK
- Maurice Maes, SIGNIFY, The Netherlands (re-elected as Vice-President)
- Joerg Minnerup, Trilux, Germany
- Miguel Aguado Pelaez, Lutron, UK
- Zoltán Pilter, Tungsram Group, Hungary
- Jan van Rompay, Lumileds, The Netherlands
- Mark Oliver Schreiter, ERCO, Germany
- Lars Stuehlen, LEDVANCE, Germany (re-elected as Treasurer)
- Carlo Urbinati, ASSOLUCE, Italy
- Dr. Jürgen Waldorf, ZVEI, Germany

"I am honored to be re-elected President and look forward to continue collaborating with the Board and with regulators and customers to foster trust in the professionals of Europe's lighting industry and our capacity to deliver quality lighting for all," said Lionel Brunet.

Job Opportunity: Technical Manager – LightingEurope

LightingEurope is looking to recruit a full-time Technical Manager to join the Secretariat team based in Brussels.

LIGHTINGEUROPE
THE VOICE OF THE LIGHTING INDUSTRY

About the successful candidate. You have:

- an engineering background
- minimum 5 years' experience in lighting, preferably in a manufacturing company (R&D) or a test house broad understanding of multiple technical parameters and regulatory requirements impacting lighting (e.g. performance, quality, substances, data/software)
- excellent communication skills in English, both written and oral (additional languages are a plus). You have demonstrated experience in:
  - drafting content – you can adapt your messaging to both an audience of technical experts and an audience of laymen
  - effectively communicating your proposals in meetings both with technical experts and with laymen
  - public speaking experience is a plus
- experience in working in international teams
- experience in participating to meetings with diverse stakeholders, you are a good listener and are skilled at fostering consensus
- active social media presence is a plus

Personal skills: customer-oriented, team player, proven ability to work independently and deliver on time to targets, proactive, prepared to think outside the box, good sense of adventure.

About the role: You will join the LightingEurope Secretariat team and will...

- liaise with the policy team to monitor and evaluate upcoming EU regulatory developments, analyze the potential impact for LightingEurope members and recommend actions for LightingEurope
- liaise with LightingEurope members to evaluate EU policy developments and foster a LightingEurope position
- liaise with EU regulators to explain lighting technology and LightingEurope recommendations
- draft LightingEurope advocacy and technical material (e.g. position papers, guidelines)
- help manage the LightingEurope working groups and subgroups – set up and manage meetings, draft agendas and minutes, support Chair and participating members to forge consensus (currently all meetings are online/ min 3 f2f meetings per working group when not in times of pandemic)

The role will functionally report to the Policy Director and Senior Policy Manager.

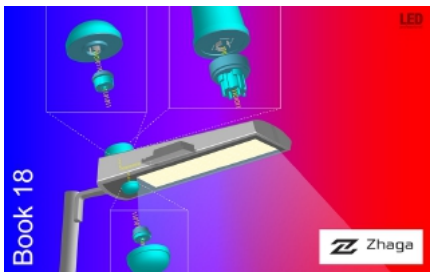
Location: The LightingEurope office is located in Brussels, Belgium and the successful candidate will be expected to be present in the office minimum 4 times per month (once current restrictions are lifted). Limited international travel may be expected.

What we offer: LightingEurope is tasked with delivering the 2025 Strategic Roadmap of Europe's lighting industry and you will be at the heart of our activities, working both with industry leaders and technical experts on the one hand, and with EU regulators on the other to shape a positive business environment.

We are a vibrant and ever-evolving organization, value for members is what drives the work of the Secretariat. We map industry, business and regulatory trends and adapt our activities to develop and deliver new products and services for our members and the wider industry. You will join a dynamic young international team, composed primarily of policy experts, with a strong network in the Brussels policy arena and the industry. We offer a competitive salary and benefits package in line with Belgian living standards.

How to apply: Please send your CV and a cover letter explaining the value you can contribute to LightingEurope members by EOB 25 May 2021 to Ourania Georgoutsakou, Secretary General (ourania.georgoutsakou@lightingeurope.org). Please state "Application Technical Manager – [your name]" in the email subject line. Only shortlisted candidates will be contacted due to limited capacity. Please include in the body of your email: "I hereby agree for my personal data to be processed by LightingEurope for recruitment purposes" – in line with personal data rules we must have your written consent to follow up on your application. LightingEurope will not keep your CV and cover letter on file – all information of non-successful candidates will be deleted from our records. ■

Zhaga's Book 18 Ed. 3.0 Approved



Zhaga Steering Committee has approved the 3rd edition of the popular Book 18 specification for outdoor luminaires. The new edition allows for architectures combining an ANSI C136.41 dimming receptacle with a Zhaga receptacle next to the architectures already specified in Ed. 2.0. Additionally, Zhaga-D4i certification of hybrid luminaires as well as control devices with an ANSI interface have become available.

Zhaga introduced Book 18 Ed. 2.0 in November 2019 with the aim to create an interoperable system of an outdoor luminaire and sensing/communication modules, by defining the mechanical interface, the communication protocol and allowable power budgets. More than 20 luminaire manufacturers have meanwhile certified close to 100 luminaire families making tens of thousands Zhaga-D4i certified product types available to the market.

Addressing additional market needs for hybrid luminaires that have both a "Zhaga connector" and an "ANSI receptacle", Zhaga experts developed Zhaga Book 18 Ed. 3.0. Hybrid luminaires support applications that leverage existing lighting controllers focused on ON/OFF/Metering with additional features such as environmental sensing and area security monitoring. They also enable use cases that require the energy metering in a device to be calibrated on a regular basis and devices that need more power than currently available through Book 18 Ed. 2.0. The hybrid solution still offers the sensing use cases based on the Zhaga socket, that can also be positioned underneath a luminaire, and maintains the interoperability promise of Zhaga Book 18 Ed. 2.0.

Book 18 Ed. 3.0 is again based on a liaison between the Zhaga Consortium and the DALI Alliance (DiiA), the owners of the DALI lighting protocol. Through Book 18 Ed. 3.0, Zhaga-D4i certification of hybrid luminaires as well as control devices with an ANSI interface and Zhaga-D4i certification have become available by the accredited Zhaga test houses listed on the Zhaga website. Book 18 Ed. 3.0 as well as Zhaga-D4i luminaire certification is available to Regular and Associate Zhaga members. For Zhaga-D4i node certification, additionally, DALI Alliance membership is required.

Zhaga sees Book 18 and the liaison with the DALI Alliance as enabling smart cities by creating a platform that connects luminaires, drivers, control & communication devices and sensor input nodes. If you will; becoming the backbone of the smart city. Adding the ANSI interface gives this ecosystem further flexibility, allowing designers and specifiers options that will best suit their region of world and local compliance needs. ■

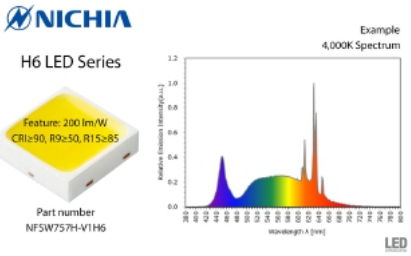
SOLUTIONS

NICHIA's Advanced Phosphor Technology LEDs Deliver Industry's Highest Joint-boost in Color Rendering and Efficacy

NICHIA, the world's largest LED manufacturer and inventor of the high-brightness blue and white LEDs, announces its H6 series. Implemented into NICHIA's 3030 mid-power 757 package to start, the new family of LEDs delivers the highest multi-level boost in color rendition and efficacy whilst maintaining the outstanding lifetime expected from NICHIA.

H6 LED series raises the bar in lighting quality and overall effectiveness in discerning environments. Indeed, the H6 series delivers a color rendering index (CRI) of 90 while maintaining a level of efficacy seen in standard CRI 80 LEDs.

NICHIA, the world's largest LED manufacturer and inventor of the high-brightness blue and white LEDs, announces its H6 series. Implemented into NICHIA's 3030 mid-power 757 package to start, the new family of LEDs delivers the highest multi-level boost in color rendition and efficacy whilst maintaining the outstanding lifetime expected from NICHIA. Indeed, the H6 series delivers a color rendering index (CRI) of 90 while maintaining a level of efficacy seen in standard CRI 80 LEDs.



Regularly, lighting professionals have needed to sacrifice lumen efficacy when seeking elite color quality in LEDs. NICHIA's latest LED family provides better all-round performance for those luminaires targeting discerning environments, especially in shops, restaurants, hotels, and galleries/museums, and restroom settings where color rendering and energy savings are imperative design considerations. The solutions are particularly useful for general Illumination fixtures (such as troffers, tracks, downlights, spots, and desk lights among others) to boost the vividness of rich colored merchandise, artworks and furniture, as well as to set mood, add accents or grab attention in retail and hospitality venues.

NICHIA's new H6 series takes advantage of a unique red narrow band phosphor technology, among other semiconductor processes and packaging techniques, to develop LEDs which achieve a color quality better than traditional CRI 90 LEDs with R9 content greater than 50 while maintaining an efficacy better than many CRI 80 LEDs. In fact, the 0.2W H6 series delivers a typical luminous efficacy of 200 lm/W, a 20% increase in efficacy compared to many CRI 90 LEDs available in the market.

"Generally speaking, there is usually a trade-off between achieving high lumen efficacy and a high CRI. By optimizing the light spectrum, NICHIA has made a technology breakthrough to deliver both superior luminous

efficacy and high CRI," said Yuji Itsuki, General Manager of Marketing, NICHIA. "The NICHIA brand has been at the forefront of lighting innovation for decades and these new additions to the company's LED portfolio are so exciting because they continue to offer unrivalled high-quality illumination, reliability and energy efficiency."

"By optimizing the light spectrum, NICHIA has made a technology breakthrough to deliver both superior luminous efficacy and high CRI," said Yuji Itsuki, General Manager of Marketing, NICHIA

NICHIA's H6 LED solution in a 3030 mid-power 757 package is now available in OEM quantities. For additional information, customers can contact their local NICHIA office.

Notes: (1) NICHIA's 757 3030 platform is a 3.0 x 3.0mm form-factor that works for many of its customers. (2) In addition to NICHIA's technology, the company's H6 LEDs incorporate TriGain® technology, a potassium fluorosilicate (PFS) based phosphor technology licensed to NICHIA through a strategic partnership with GE Current. ■

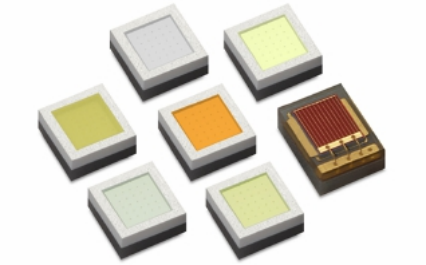
New Cree LED™ XLamp® XP-P LEDs Deliver Breakthrough Intensity

XLamp® XP-P LEDs deliver breakthrough levels of intensity and optical control in a familiar XP footprint. With up to 700 lm available at maximum current from a very small LES, the XP-P enables tighter beam angles and much longer throw distances than any previous XLamp LED.

XP-P LEDs are built to last in extreme applications, with high operating temperature limits and excellent sulfur resistance. XP-P LEDs are optimized for lighting applications that require extreme levels of intensity, including aftermarket automotive, professional portable, architectural and entertainment. ■

Tiny and Powerful LUXEON Rubix LEDs Raise the Bar for CRI, Lumens, and Efficacy with Addition of Lime and PC Amber

Lumileds has introduced two new colors – PC Amber and Lime – for its very small and very powerful LUXEON Rubix LED portfolio. The 1.4 square millimeter footprint is almost pixel like and belies the light output that's possible from this high-power LED. There are 6 color options plus white in the portfolio.



LUXEON Rubix maximizes design flexibility and enables solutions that simply aren't possible with pre-set multi-color packages. The high power, uniform focal height, and narrow angle beam control contribute to enabling new, more efficient, and impactful designs.

"LUXEON Rubix is the most important device for our next generation L2 light engine and architectural lighting product development. The compact form factor and extremely high drive current set it apart from other color options," said Alex Wang, President & CEO at General Luminaire Co. Ltd.

"The addition of Lime and PC Amber create opportunities to boost CRI, brightness, and efficacy. Objects will often appear more vivid when Lime is used instead of white (RGBL vs. RGBW). Lime and PC Amber achieving 90+CRI at 3000K, 4000K or 5000K is no problem and in a 6-channel solution, 95+ CRI is possible," said LP Liew, Product Marketing Manager at Lumileds.

To further support development with LUXEON Rubix, Lumileds also offers level 2 solutions through its Matrix Program. Aluminum-Nitride boards with high thermal conductivity unlock the full potential of LUXEON Rubix and by having Lumileds select the LEDs at the factory, all binning and selection issues are eliminated for the luminaire manufacturer.

Each LUXEON Rubix delivers outstanding flux performance. The new PC Amber delivers 250 lumens and Lime a stunning 510 lumens at 1500mA. Typical output for other colors at 1500mA and Tj 85°C is: Red 85lm, Green 310lm, Blue 112lm, and Royal Blue 1635mW. Typical output for white is 440lm at 93lm/W.

Complete product specifications are available in the datasheet and at the LUXEON Rubix web page.

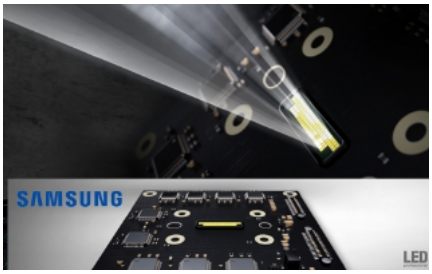
LUXEON Rubix is in-stock and available from your preferred Lumileds distributor. ■

PixCell LED for Intelligent Headlight Systems to Enhance Road Safety

Monolithically-integrated PixCell LED design provides precise selective lighting control to improve driving visibility and help drivers better respond to surrounding environments.

Samsung Electronics, a world leader in advanced digital component solutions, announced PixCell LED, a new automotive LED module optimized for intelligent headlights, such as adaptive driving beam (ADB) systems. ADB headlamps powered by Samsung's PixCell LEDs will help improve driver visibility and safety to enhance the overall driving experience at night and in poor weather conditions such as fog or heavy rain.

"Much more than a simple automotive lighting source, Samsung's PixCell LED is based on new lighting technology designed to improve road safety and driving convenience. Beginning with PixCell LED, we will introduce tailored lighting solutions well-suited for future automobiles, including electric and autonomous vehicles." said Un Soo Kim, Senior Vice President, LED Business Team at Samsung Electronics.



ADB is an advanced driver assistance technology designed to help secure maximum driving visibility. In order to prevent glare to other drivers, ADB automatically adjusts headlight beam patterns when it detects any object near a moving vehicle, thereby preventing any unnecessary glare. Recent developments in future automotive technologies, such as autonomous and connected driving, have been raising the bar for vehicle safety standards and ultimately boosting demand for ADB systems.

Leveraging Samsung's longstanding expertise in semiconductor technology, the new PixCell LED can monolithically integrate more than 100 ultra-small segments into a single LED chip, while making the light-emitting area significantly smaller. These LED segments are

separated by a silicon wall to prevent optical cross-talk, and in turn, offer superior contrast for much greater driver visibility. Each segment functions like a pixel to meticulously control light distribution, as it distinguishes on and off areas so that the beam from the headlight only illuminates the exact location where it is needed.

With the light-emitting area shrunk to 1/16 of conventional discrete LED modules for ADB systems, the PixCell LED can reduce the headlamp size by 30-50%, allowing greater freedom in designing sleeker and more elegant lamps.

The light distribution and brightness levels of the PixCell LED are designed using automotive lighting software, making them easily adjustable to meet diverse regulations and requirements for automotive lamps around the world. Based on a single standard headlamp design, lamp makers can customize light output to suit varying design needs and enjoy reduced lead time for development, production, supply and time-to-market. Samsung has begun shipping its PixCell LEDs to lamp manufacturers for use in next-generation electric cars and has already provided enough PixCell LEDs to light more than 300,000 electric vehicles. ■

New High-Brightness Front and Rear Automotive Lighting Module

LG Innotek (CEO Cheol-dong Jeong) announced on the 20th that it had developed 'Nexlide-E,' an automotive lighting module that produces bright and uniform light.

This automotive lighting module is made of three parts. An LED package, which is a light source, is mounted on a thin substrate. Then, optical resin covers the package and substrate for protection. Lastly, a thin optical film is attached on top of the package to spread the light brightly and evenly. The module can be used as taillights, stop lamps, and headlights.

The Nexlide is LG Innotek's automotive lighting service brand that has the meaning of a next-generation light source. The name was produced by combining the words 'Next,' 'Lighting,' and 'Device.' LG Innotek provides automotive lighting module products as well as customized solutions such as optical device design, lighting design proposal, and more with the Nexlide brand.

The Nexlide-E is 63% brighter than the previous product and produces more uniform light. LG Innotek applied a high-performance and high-reliability optical film to improve the lighting performance. The company's micropatterning technique was used in the film to give a variety of lighting effects.

Due to its brightness, this lighting module can replace multiple automotive lamps with different brightness standards into one module. This can improve space efficiency and allow more design variations of a vehicle's lamps.

The maximum brightness of the Nexlide-E has been raised from 80 cd (candela, the unit of brightness) to 130 cd, making it 63% brighter than the previous product. This satisfies the brightness standard of taillights, turn signals, and stop lamps. The stop lamps have the strictest brightness standard. In Europe and North America, they are required to be 110 cd or higher. This is because stop lamps must be recognizable in any circumstances for driving safety.

The Nexlide-E is also power efficient because the module is bright enough with a small amount of electricity. This is particularly important for electric and hydrogen vehicles in increasing their mileage range (corresponding to fuel economy in conventional vehicles). Also, car manufacturers can replace different lightings of a vehicle such as a taillight and stop lamp into one lighting module using the Nexlide-E. The product's high brightness makes this possible by satisfying the different brightness levels of taillights, stop lamps and turn signals.

To achieve such a bright and uniform light, LG Innotek developed a new optical film for the Nexlide-E. An only 0.2mm thick film produced with the company's unique micropatterning technique is attached to the automotive lighting module. Different types of the optical film create various lighting effects. The micropatterns can be changed according to the type of optical film to increase brightness by collecting the beam, produce a surface light source by diffusing the light or even produce a three-dimensional light shape. With optical films, LG Innotek can produce customized lighting modules without complex design changes or using additional components such as an inner lens.

LG Innotek will leverage the Nexlide-E to expand its share in the automotive lighting module market. To do so, the company has been active in promotions targeting global car makers in the U.S., Japan, Europe and South Korea. The first vehicle equipped with the Nexlide-E is expected to be mass-produced in the latter half of this year. LG Innotek is also focusing on the development of next-generation lighting products. The company is developing another type of optical film that further raises the brightness and uniformity of the light. It is also developing the Nexlide-C+, a 3D lighting module that produces 3D light shapes without any devices such as a half-mirror that assists 3D effects within a lamp.

“The Nexlide-E is an innovative product that satisfies customer needs for distinctive automotive lighting designs that give character to vehicles. With the Nexlide brand, LG Innotek will continue to deliver a safe and enjoyable driving experience with the automotive light source solution service,” said Insoo Ryu, VP, Head of the Automotive Components & Electronics Business Division

Global Market Insights, a market research institute, predicts that the automotive lighting market will grow from USD 32.6 billion in 2021 to USD 38.5 billion in 2026. ■

Exchangeable Light Engine for Automotive Headlamps

With its new eXchangeable Light Engine, OSRAM Continental is now extending and simplifying the integration of LED lighting solutions to entry-level vehicle classes. The automotive lighting specialist aims to create a new industry standard where LED headlights are to become the norm in automotive lighting – to make driving at night significantly safer.

At a time when traditional headlamp technologies are gradually being replaced by LED systems, automobile manufacturers are under increased cost pressure. With the eXchangeable Light Engine, OSRAM Continental answered this challenge by making LED lighting available for entry-level cars and basic trim levels. The company plans to leverage this flexible solution of it to further drive the change to LEDs as the standard lighting in the market.

Efficiency and flexibility for a variety of applications

The eXchangeable Light Engine can be used for all vehicle classes thanks to a modular and scalable product approach including three performance versions for flexible lighting design. Its highly efficient thermal design allows for optimal system integration. ■

BIOS Launches the Next Generation of Icarus™ LED Grow Lights and Expands its Portfolio of DLC Listed Fixtures

BIOS, a NASA spinoff and leader in engineering horticultural lighting built with the grower in mind, announced its next generation of DLC certified BIOS Icarus LED Grow Lights.

With higher efficacy, industry leading uniformity and superior long-term performance, BIOS Icarus fixtures provide everything a grower needs to ensure successful production for years to come. By attaining the DLC listing for these products, growers can rest assured they are purchasing the most reliable, energy efficient and safest products available.

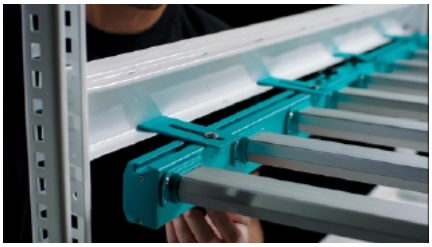
Commercial growers purchasing DLC certified grow lights receive the following benefits:

- Qualification for state and local energy rebates and incentives
- A full 5-year warranty
- Third-party validated testing of performance and reliability

”DLC listed grow lights provide the grower with accurate third-party performance data, a sense of security and a menu of choices that a grower can trust.” – Doug Oppedal, Owner, CEA Lighting Specialist with Doug Oppedal Consulting

What makes BIOS Icarus™ a game changer for commercial growers?

- Cleanable glass lenses to ensure maximum light output and uniformity
- IP66 wet rated to enable years of operation in harsh growing environments
- BIOS RapidRack™ mounting system– Save up to 12hrs of installation time* with a tool free mounting system (*Time calculation based on installing 200 Icarus™ Li2 or LLi)



Sean Tegart, President and CEO of BIOS believes having a third-party validation through DLC benefits the market as a whole. “BIOS strongly supports DLC and the service it is providing to the industry. We are proud to offer a full portfolio of DLC listed products so growers are able to have the best data available when making lighting decisions.” According to Mr. Tegart, there are several lighting manufacturers who may be disingenuous in how they present their performance data. “With a DLC listing, a grower can have confidence the data they are being given is what they will see in their facility” he says. ■

TRENDS

Photobiomodulation Technology in the Treatment of Alzheimer's Disease

REGEnLIFE, a company specialized in the research and development of innovative photo-medical technologies for the prevention and treatment of neurodegenerative diseases, announced the promising results of the pilot clinical trial evaluating its technology in Alzheimer's disease (AD).

REGEnLIFE, a company specialized in the research and development of innovative photo-medical technologies for the prevention and treatment of neurodegenerative diseases, announces the promising results of the pilot clinical trial evaluating its technology in Alzheimer's disease (AD). The results were presented by Professor Jacques Touchon, scientific advisor on the trial, at the 15th International Conference on Alzheimer's and Parkinson's Diseases (AD/PD 2021), held online from March 9 to 14, 2021. REGEnLIFE's innovative non-invasive technology, evaluated in a therapeutic trial, is based on photobiomodulation, targeting both the brain and gut via a helmet and abdominal device. This cutting-edge medical device, RGn530, stimulates cells in the brain and gut and regulates inflammation - to improve cognitive functions and behavior. It targets inflammation of the gut-brain axis, which is believed to be linked to the development of AD and other neurodegenerative diseases.

The trial enrolled adult volunteers aged 55 to 85, with mild to moderate Alzheimer's disease. They were equipped with a helmet and a photobiomodulation abdominal belt; the patients benefited from a total of 40 sessions; these lasted for 25 minutes and were spread over a two-month period. The volunteers were evaluated in a series of tests during the trial and up to one month after treatment ended. This double-blind, randomized, monocenter, placebo-controlled clinical trial began in 2018; it ended prematurely in 2020 due to the COVID-19 pandemic. Out of the 64 planned patients, 53 were randomized into two groups (treated and placebo) and 43 patients benefited from the full duration of the treatment.

The primary efficacy endpoint was measured by the evolution of the total ADAS-Cog score, (Alzheimer's Disease Assessment Scale), between inclusion and the end of the two-month period of treatment. The REGEnLIFE RGn530 device was shown to be safe; no major side effects were reported. Compliance with treatment sessions was very high for the vast majority of patients (92%). This level of compliance also confirms the good tolerance of the device. While the primary efficacy endpoint was not statistically met, there was a clear improvement trend in a set of cognitive functions. The results of this pilot study showed that REGEnLIFE's technology is safe and well-tolerated by patients. These very encouraging safety and efficacy results will now be confirmed in a pivotal or phase III clinical trial.

Guillaume Blivet, Co-founder and President of REGEnLIFE

"The therapeutic strategy for AD should involve several targets. Drug treatments targeting the two characteristic proteins of the Alzheimer's process (beta-amyloid and tau proteins) must be supplemented by other therapies - targeting less specific but very important mechanisms in the pathophysiological AD cascade, such as inflammation and oxidative stress," said Professor Jacques Touchon, neurologist and psychiatrist, scientific advisor on the clinical trial. "REGEnLIFE's photobiomodulation technology acts at the early stages of this cascade, (mitochondria, inflammation, oxidative stress), and could be the non-drug complement to the next-generation therapeutic strategy."

"This technology also makes it possible to act on both the brain and the gut, a significant advantage when we know the important role of the gut-brain axis and microbiota in neurodegenerative pathologies," said Professor Jacques Touchon.

A unique photobiomodulation technology for the treatment of Alzheimer's disease: Photobiomodulation is based on photonic emissions in the near-infrared, it has already shown analgesic, anti-inflammatory and healing properties. One of the most reproducible effects is the overall reduction in inflammation, especially in the brain. REGEnLIFE's technology could therefore be used on brain diseases and on pathologies linked to neuroinflammation. REGEnLIFE developed this device employing this scientific approach, using medical technology never before applied to neurology.

"There are increasing scientific data to endorse the hypothesis that the gut-brain axis is involved in the development of AD and other neurodegenerative disorders; we also believe that some forms of electromagnetic emissions could prevent and treat this disease. Our initial clinical data, coupled with all our preclinical proof of concept studies, led us to pursue a pivotal clinical study in AD and to consider working on other neurological diseases," said Guillaume Blivet, co-founder and president of REGEnLIFE. "To accelerate this new phase in our development and to shortly gain early market access, we are preparing a new funding round before the end of 2021."

According to Alzheimer's Disease International, 35 million patients worldwide have AD. The annual cost of the disease worldwide is estimated at €850bn (USD1.02tr). Currently, there are no treatments to cure Alzheimer's.

In order to address public health issues related to a disease that affects elderly and vulnerable people, REGEnLIFE chose to develop a non-invasive technology with low constraints for patients. The cost of this device is expected to be reasonable for patients and national healthcare systems.

About REGEnLIFE: REGEnLIFE specializes in the research and development of innovative photo-medicine technologies for the prevention and treatment of neurodegenerative diseases. The company aims to provide a photo-medical technology targeting both the brain and the gut; in particular for the treatment of Alzheimer's disease. REGEnLIFE's innovative and non-invasive technology, currently in a clinical trial, is based on combined infrared waves emitted at the skull and abdomen levels,

through a helmet and belt device. REGEnLIFE brings together a team of multidisciplinary partners, including experts and researchers from many fields: engineering, optics, photonics, electronics, new technologies, physical sciences, public health, medicine, neurology and neurosciences. The company is supported by private investors, the French investment bank Bpifrance and by the Occitania Region of France, in several R&D projects. REGEnLIFE raised €3M (USD3.6M) in 2018 from business angels and family offices. The REGEnLife team of eight is based at the BIC incubator in Montpellier, France. www.regenlife.com ■

Quantum Dots Launch For The First Time In Lighting

Vancouver based, Nano-Lit Technologies lighting system adjusts wavelengths and color temperature throughout the day to support the alignment of the body's circadian rhythm to the day-night cycle. SENSO Lighting fixtures with Nano-Lit light engines address features within the WELL Light concept of WELL v2. The effect of light on people is an emerging area of study and to date we know more about its effect on plants than people in buildings.

Thus, Nano-Lit is working with circadian rhythm researchers at five leading US and Canadian universities to study lighting as part of the treatment regimen for cancer, delirium, insomnia, depression and aging-related conditions. Dr. Chris Mason, Chairman and Member of the Board of Directors, will for the Nano-Lit investigation leverage some of the research protocols Dr. Mason developed for the NASA Twin Study, where he was the Principal Investigator for the genetics and gene expression components of the research - including responses to circadian rhythm disruption.

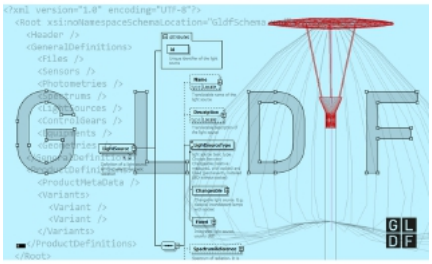
Quantum Dots, which facilitate improved wavelength control as well as minimize blue light more than standard LED phosphors, have been used in Biotechnology for screening for decades and in the past five years have been used in the Samsung QLED displays. IWBI is leading the global movement to transform buildings and communities in ways that help people thrive. IWBI™ delivers the cutting-edge WELL Building Standard™, the leading global rating system and the first to be focused exclusively on the ways that buildings, and everything in them, can improve comfort, drive better choices, and generally enhance, not compromise, health and wellness. WELL also works alongside LEED to ensure that buildings and communities preserve energy and precious resources for a brighter and more equitable future; while supporting enhanced human health, well-being and performance. To date, over 3,800 projects with more than 450 million square feet of registered space are participating in WELL in 58 countries.

"Lighting plays an important role in keeping us energized and maintaining our internal clocks," said IWBI™ CEO and Chairman Rick Fedrizzi. "We're excited to now experience a circadian lighting solution within our own global HQ." ■

DIAL and RELUX are Working Together to Develop a New Data Format for Lights and Sensors, the Global Lighting Data Format (GLDF)

GLDF is an open, free format that can be used across the entire lighting industry and meets the latest BIM process requirements. Manufacturers, planners and even software manufacturers will benefit from this new format.

Impetus and initial situation: Until now, manufacturers have had to deal with the fact that users require internal product information in different formats and for different purposes. Planners and designers use several different programs for different purposes and expect product data to be available and, of course uniform, across all applications. Software manufacturers require comprehensive and the most up to date product information. This data must include all information required for the respective purpose. The Global Lighting Data Format (GLDF) provides the following advantages for everyone involved: Manufacturers only need to maintain and offer a single format. All processes operated by manufacturer data can access the information from the GLDF. Planners can find all information on a product in the GLDF. The file can be used by all programs and applications. The information is always identical, ruling out differences between different file versions. Software manufacturers can find great information for their (design) programs. Manufacturers are incentivized to maintain the information and keep it up to date as they no longer need to create new formats for many different purposes.



Current status of electronic lighting documentation: Various descriptions for lights are currently available for different purposes. Standard photometry formats such as Eulumdat, LM63, TM-14 or UNI 11733-2019 are available for creating technical data sheets or calculating a lighting system. These formats document physical properties of lights and lamps. Measured properties are presented and can be interpreted using formulas and standardized application rules. These formats contain very little further information that would be required for a complete BIM-process, including system design, commercial processing or facility management. For information required by retailers, for example, there is the ETIM format which is common in Germany and also used in other countries. This is designed for data exchange between the manufacturer and retailer, and compiles product descriptions. This format cannot be used for light planning. Modern data formats that are used in CAD and lighting design programs include ULD (DIALux) ROLF (RELUX), RFA (Revit) or even IFC (OPEN BIM). These formats combine different requirements. In lighting design programs, light is calculated and the most complete product information possible is given for selection and ordering. In contrast, the RFA and IFC data formats try to map the product in the CAD and BIM process without sufficiently considering the lighting technology.

Current status of the new Global Lighting Data Format (GLDF): The new Global Lighting Data Format (GLDF) has been developed to fully map lights and presence or movement sensors for all purposes. Preliminary work from various committees, such as the ZVEI BIM workgroup, has been

incorporated. Part of the GLDF is, of course, photometric and spectral information as well as geometrical, electrotechnical, commercial and maintenance information. The features are described in CEN TS 17623, "BIM Properties for lighting - Luminaires and sensing devices". Further parameters can also be saved. In terms of BIM, a GLDF can be used in a project from the first design phase to recycling. DIAL and RELUX have designed a data structure that can map all aforementioned parameters and therefore makes data exchange between applications and stakeholders possible. In order to reach the largest possible number of users, the format and related documentation are provided free of charge. The format will continue to be curated by the participating companies and further developed according to requirements. The documentation should be released over the course of 2021. A beta phase of the format is to start in the first half of 2021. Software manufacturers (light planning, CAD, PIM) and lighting manufacturers must then implement and offer this format in their systems.

Set-up & structure: The GLDF is set up in an XML structure (Extensible Markup Language). This is ideal for displaying hierarchically structured data. Other advantages are readability for people and machines, platform independence and very wide distribution. The GLDF is a container format within which the data supplier can integrate all content. These include texts, images, light distribution curves (LVK), spectra, 3D models, etc. A product can also contain different supplementary information. For example, a light can be described as a cuboid with length, width and height, but a detailed 3D model can also be provided. The reading application can then decide whether to display a simple or a complex model. Products can be simple or complex depending on real life requirements. This means it is also possible to map a simple recessed luminaire as well as a complex lighting system with many light exits, which is individually dimmable and also color-changing for "Human Centric Lighting". Furthermore, systems can also be equipped with motion sensors and emergency lighting units. The structure is defined in such a way that individual elements as well as the entire content can be signed. This makes it possible to see whether the content has been changed. This gives the manufacturer or the supplier of the data and planners great internal security when using GLDF files. If parts have been changed, e.g. power input, LVK or manufacturer designation, this can be identified immediately when checking the signature. As well as the documentation, an XML Scheme Definition (XSD) is also provided. Software developers can therefore easily implement the GLDF interface into a PIM system (Product Information Management). Both the structure and data types are defined within the XSD. ■

WHITE PAPER: Measuring UVA & Violet LED Light Sources

As the development of new UV LED sources continues at an ever-growing pace, so do the industrial applications that utilize them. UV LEDs are being put to work in various industrial processes, medical applications, and disinfection solutions. Efficient utilization of the UV radiation requires good measurement tools. However, accurate light measurement in this spectral range presents challenges, such as how to accurately measure the irradiance if the wavelength of the light is not exactly known.

This whitepaper discusses the key considerations in the fields of:

- Irradiance measurement
- Irradiance uniformity mapping
- Dosage measurement of a static or moving source

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It introduces a new irradiance sensor that allows the user to measure light sources without knowing much about their spectra and also supports simultaneous measurement of different light sources (e.g., LEDs with different peak wavelengths and bandwidths). ■

LpS Digital: Lighting Conference & Exhibition 2021

LpS Digital is the unique and first digital lighting conference and exhibition available to viewers 24 hours a day, 7 days a week. LpS Digital presents current, high-quality content about lighting technologies, design and applications, and acquaints the viewers with the latest trends in product developments and applications.

Experience the Future of Light

Like the LED professional Symposium +Expo and Trends in Lighting Forum &Show that took place at the Festspielhaus in Bregenz/Austria every year since September, 2011, LpS Digital is meant to approach and support the complete value chain in the global lighting industry. When it comes to Technological Design, LpS Digital's goal is to provide Corporate Managment, Technical Management, R&D and Production/QM within the global lighting manufacturing industry with top notch technical knowhow, primarily on a component level. In terms of Lighting Design, LpS Digital will show best practice for Architects, Lighting Consultants, Electrical Consultants, Lighting Designers, Lighting OEMs, IT/IoT System Integrators and students. The editors focus on Human Centric Lighting, Connected Lighting, Smart Controls, Internet of Things, Light as a Service and much more.

Unique Global Reach in the Lighting Sector

VIRTUAL CONFERENCE
The authors of contributions accepted by the program management will be invited to give a presentation and, if appropriate, to write a qualified article. Each presentation will be announced to the industry and/or design channel contacts and followers immediately after publication.

VIRTUAL EXHIBITION
Virtual exhibitors have the possibility to present their products and/or services. The maximum length of the presentation is 20 minutes. Each product/service video is announced to the industry and/or design channel contacts and followers immediately after publication.

Lighting Industry & Technology Channel

With the Industry/Technology channel, over 30,000 contacts in the lighting sector are targeted and addressed. The opt-in databases are highly selective, highly qualified and address key persons in the respective channel.

- Magazine: 30,000
- Newsletter: 27,000
- Online: 30,000/month
- Twitter: 22,000
- LinkedIn: 11,700

Lighting Design Channel

With the Design channel, over 30,000 contacts in the lighting sector are targeted and addressed.

- Magazine: 30,000
- Newsletter: 15,000
- Online: 5,000/month
- LinkedIn: 4,600

Benefits for Conference Authors

- Global, highly-qualified target group
- Knowledge transfer at a high level
- Ideal platform for expanding the network

Benefits for Virtual Exhibitors

- Global, highly-qualified target group
- Immediate promotion of innovations and novelties
- Participation in the LpS/TiL Awards
- Highly efficient promotion at no risks

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LED Business in Focus – Un Soo KIM, Senior Vice President of SAMSUNG Electronics

Un Soo KIM
Un Soo KIM is Senior Vice President of Samsung Electronics.
He has been the Head of the Strategic Marketing Team, Samsung Electronics LED Business, since 2018. Mr. KIM was the Head of the Brand Marketing Team, Samsung Electronics Memory Division from 2013 to 2018, and the Brand Strategic Group, Samsung Electronics Global Marketing Center from 2009 to 2010.

SAMSUNGS LED Business is one of the leading in the world. The broad utilization of their LED technologies in the consumer sector and connection with the industrial sectors' specific requirements has engaged in discussing the market developments and strategies with the global player, SAMSUNG.

LED professional: Thank you for the opportunity to interview you. We are pleased that you agreed to have this conversation with us.

Un Soo KIM: Thank you for reaching out.

LED professional: Let's start right away by asking how the LED market is structured today. Where are the growth markets and which areas are tending to stagnate or even decline?

Un Soo KIM: As all of us have witnessed, the overall LED market has been growing slowly as it approaches market maturity. However, I am still seeing major opportunities out there for LEDs. Despite an overall static pace of growth in general lighting, technology advancement will continue to maintain LED at a level up, as the industry-standard in lighting performance. Take a look at light efficacy, the key parameter of LED lighting performance. It keeps improving, and we're one of the most committed improvers. In fact, Samsung's LM301B [1] has had the top light efficacy in the mid-power LED class since 2017. Besides the efficacy, an over 80 color rendering index is considered basic performance. LED component manufacturers are working hard in order to satisfy those higher customer performance requirements today in a wide variety of markets and succeeding. New markets such as horticultural and human-centric lighting are taking the lead in moving us back on a firm path towards stable growth. The demand for differentiated lighting solutions including premium and specialized lighting will continue to grow in the foreseeable future.

Figure 1: 0.2W, 3V Mid Power LED LM301B with 220 lm/W luminous efficacy and 38.8 lm @ 65 mA luminous flux

Looking at automotive lighting, the market is being fueled by the industry's embrace of the ACES (Autonomous, Connected, Electric, Shared) trends. As autonomous driving and electric vehicles get more attention, the importance of exterior lights is rapidly growing, since these lights are a key factor for enabling better and safer driving conditions.

Furthermore, the display market is gaining greater momentum, and I don't have to tell you how large this market is. Unquestionably, TV still remains the leading home entertainment device and its popularity is growing. Pure and simple, the increasing affordability of TVs is getting stay-at-home consumers to purchase higher quality and larger-sized televisions throughout the industrial world.

In addition, the signage display market is beginning to shift towards solid growth, propelled by the availability of fine-pitch technology and greater use in areas of expanded application such as home theaters, control rooms and video conference displays.

Also, transformed lifestyles are increasing the number of home offices and home classrooms, which has stimulated demand for more mobile devices including smartphones, tablet PCs and laptops. In addition, the massive roll-out of 5G technologies, which continues globally, is also accelerating demand for mobile devices.

LED professional: How has the LED business changed, from your point of view, and what are your expectations for the industry, the design and the application or user?

Un Soo KIM: As you know, it's been more than a decade since LED became the lighting standard. As the technology evolves, new applications are being developed and refined such as the expanding role of LED lighting in stimulating the growth of plants. But, while the history of LED lighting for plant growth has been rather short, and the growing season is not that long, a large number of farms are now using specialized LEDs for horticulture instead of ordinary LED lighting. Samsung introduced its first horticultural LED packages and modules in 2018 and since then, our sales in the horticulture market have grown tremendously, over 10-fold in the past year alone.

Moreover, the B2C horticulture market has recently begun to enjoy the many advantages of specialized LED lighting, too. Successful use cases abound everywhere you look. From these expe-

riences, you can get a good idea of how commercial horticulture is leading the way in extolling the virtues of LED lighting to a market even larger than originally anticipated. In fact, we're expecting this growth to extend into the next decade.

Unsurprisingly, in today's away-from-the-office world, the display business as well as the mobile device market will continue to grow. For these markets, the industry will continue to enable high competitiveness through innovative technologies, quality components, and fast time-to-market. New markets hold much potential and must also be given a lot of attention as they continue to surprise us with their steady growth.

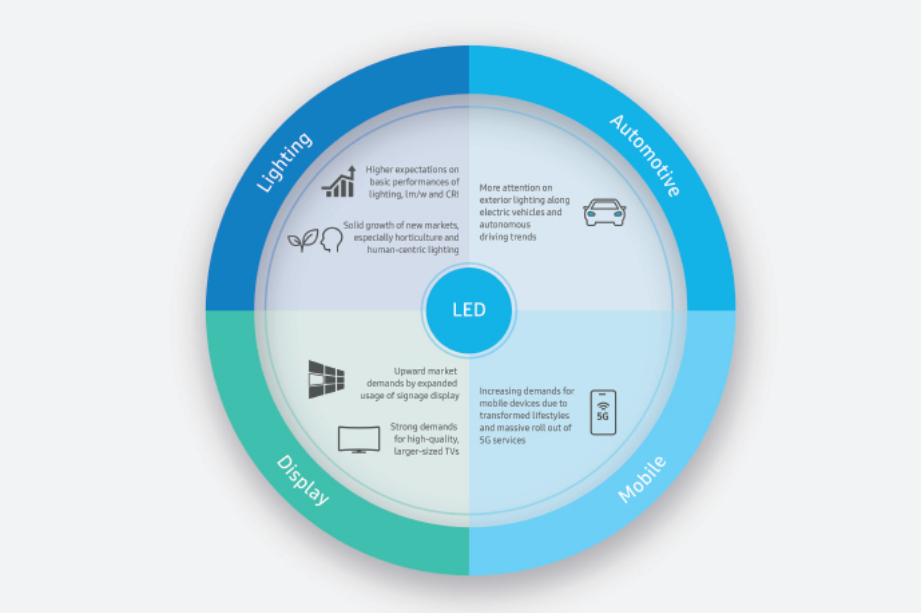

Figure 2: SAMSUNG's LED market segmentation and growth expectations

> *"New markets hold much potential and must also be given a lot of attention as they continue to surprise us with their steady growth."*
>
> UN SOO KIM

Figure 3: Horticulture lighting is a growth market for LED compoments and modules

Overall, I believe you will see more such market expansion creating opportunities for industry players in all facets of the business. In fact, there's likely to be a long maturity curve in the LED marketplace.

LED professional: What are the specific requirements that will be most prevalent in the general lighting and automotive application markets?

Un Soo KIM: I'm glad you asked that. In the future LEDs should satisfy several areas of performance, not only lm/W. With this in mind, we recently introduced human-centric LED package lineups, such as Energizing Lighting Solutions and Relaxing Lighting Solutions. The Energizing solutions apply a spectrum of light that features a maximized cyan-wavelength intensity, which helps people to be more alert and better focused. On the other hand, our Relaxing solutions feature a spectrum with minimized cyan-wavelength intensity, which promotes greater melatonin production to relax the body more after a long day.

Of course, there are other areas of growth where light efficacy plays the dominant role in enhancing product performance. For example, light efficacy is the most important factor in the automotive sector, especially in electric vehicles where driving efficiency is critical. Electric vehicles use a battery to store the energy needed to power up a car. Yet there are relatively few charging stations, and charging takes considerably more time than fueling gasoline-engine cars. So the driving range for a single charge becomes the most crucial performance aspect of an electric vehicle. Now, you might try to argue that LED lighting in cars doesn't consume much electrical power. But let's reverse our thinking here. If we save energy from even a small portion of the overall amount of power consumed, won't it still make a significant difference over long periods of driving? And isn't that even more significant when fleets of cars or traffic in an entire urban area is considered?

LED professional: Sustainability and Eco-design are modern buzzwords in the lighting world. How do you see this and what answers does Samsung offer for the challenges in these topics?

Un Soo KIM: One of the biggest advantages of LED lighting is its eco-friendliness. The absence of mercury, a long lifetime, and low energy consumption all make LED lighting what we believe is the most important sustainable lighting solution.

Un Soo KIM

As a LED components manufacturer, we are always seeking ways in which we can contribute to maintaining a healthy environment, while providing high-quality LED component solutions at the same time.

Figure 2: SAMSUNG commits to reduce carbon emissions and packaging waste

In terms of our main production lines, we set a goal to sharply reduce energy consumption and carbon emission. By optimizing several key manufacturing processes, we reduced our CO2 emissions by more than double from 2019 to 2020.

Consider another area of eco-efficiency that's often shrugged off, and by that I mean product packaging. While LED packages and modules do not require much in the way of external packaging, we realize that even such a seemingly inconsequential part of the big picture can have a distinct impact on the environment. So Samsung has redesigned its LED module packaging and now uses at least 20% less plastics in our packaging than we did last year.

LED professional: Which technological innovations will play a significant role in the individual growth areas over the next few years, and what innovations can readers expect from Samsung in the future?

Un Soo KIM: We believe one of the reasons that LED lighting technologies have been so innovative is that we have taken a very careful look at adjusting spectrum. In Samsung's view, spectrum is the fundamental element of light, so designing spectrum well determines the efficiency of the lighting that it creates. In this regard, as I previously mentioned, we've maximized the effects of horticulture and human-centric lighting by skillfully fine-tuning spectrum. And we think that spectrum technology will be the key focus for the next generation of innovation in lighting, too.

"We believe one of the reasons that LED lighting technologies have been so innovative is that we have taken a very careful look at adjusting spectrum."

UN SOO KIM

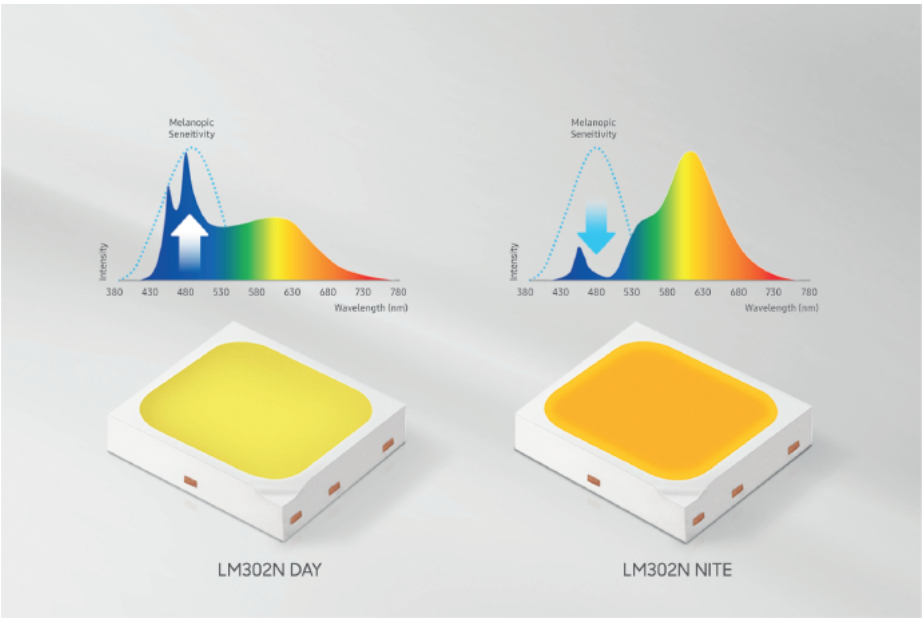

Figure 4: Spectral engineering is a crucial innovation trigger for new applications

LED professional: What's the overall strategy and vision of Samsung's LED business?

Un Soo KIM: Let me answer this by first asking you a question: What does the inseparability of light mean to people? Light affects many aspects of what we do, from the visual effects of object recognition to its non-visual impact on biorhythms including mood enhancement, sleep optimization, and health improvement. So, light is a major focus for innovation in a wide range of areas, from residential, offices and other diverse living spaces to automotive, agriculture and health care applications. It is no exaggeration to say that light is a key contributor to enabling people to have a healthy efficient day, since it is one of the most important aspects of a safe and productive living environment. Moreover, LEDs are an essential contributor to a sustainable future. Few would argue that technology, in general, needs to continue to evolve for a higher standard of living, increased environmental protection and a safer world. The same is true of lighting. Progress in the advancement of LED lighting goes beyond human convenience to the betterment of our global environment, and even in achieving a greater sense of contentment in society, overall.

Lighting, which had long been mired in the realm of lighted space, is now transforming to help us to embrace new values at the same time. Samsung Electronics **[2]** will continue to pay attention to LED's near-infinite possibilities to better understand the changing needs and problems of people over time, and enable a more environmentally friendly tomorrow.

LED professional: Thank you very much for this interesting interview and good luck for the future!

Un Soo KIM: It was a pleasure to speak with you, Siegfried. Thank you for inviting me. ■

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[1] https://www.samsung.com/led/lighting/mid-power-leds/3030-leds/lm301b/
[2] https://www.samsung.com/led/

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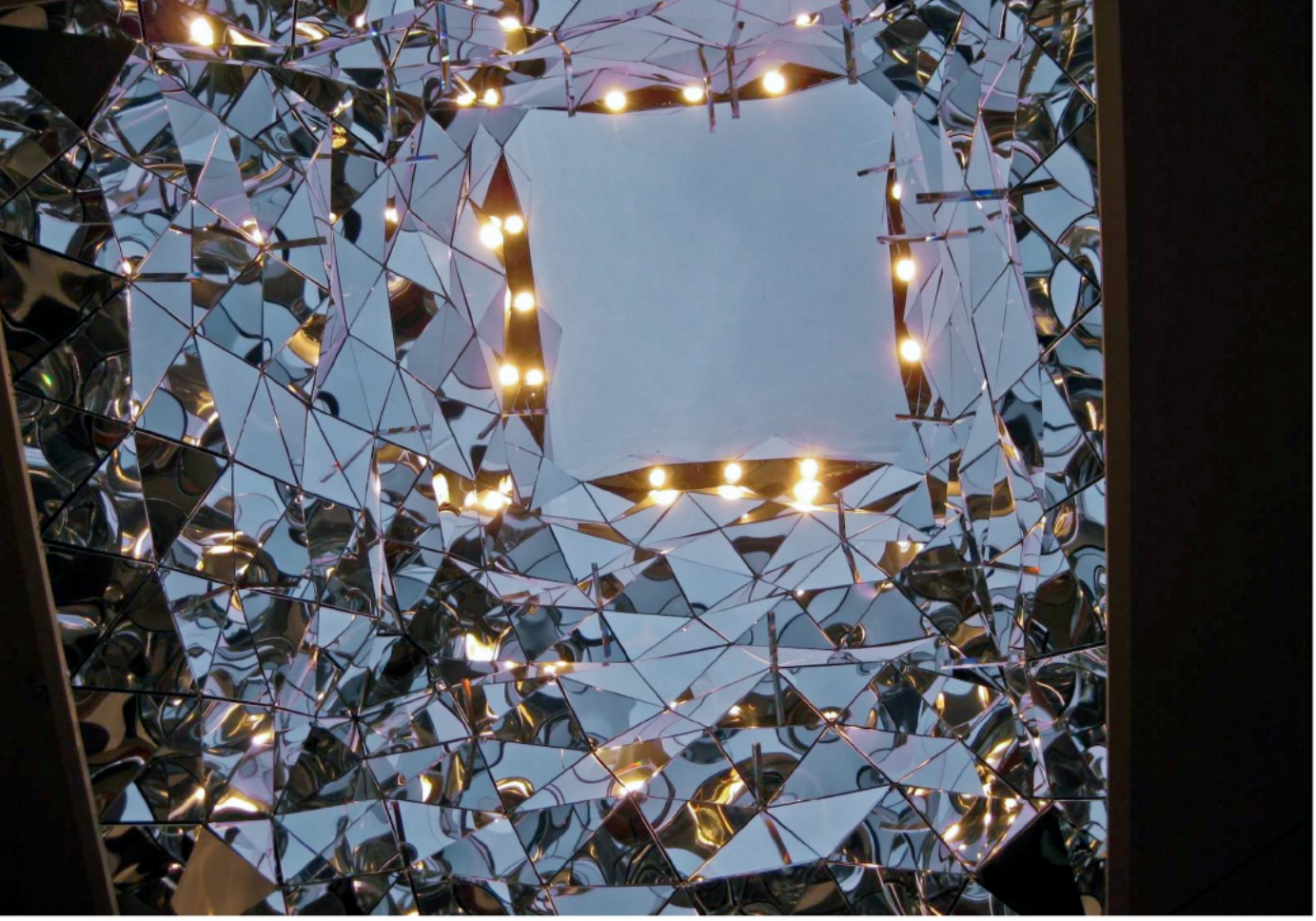

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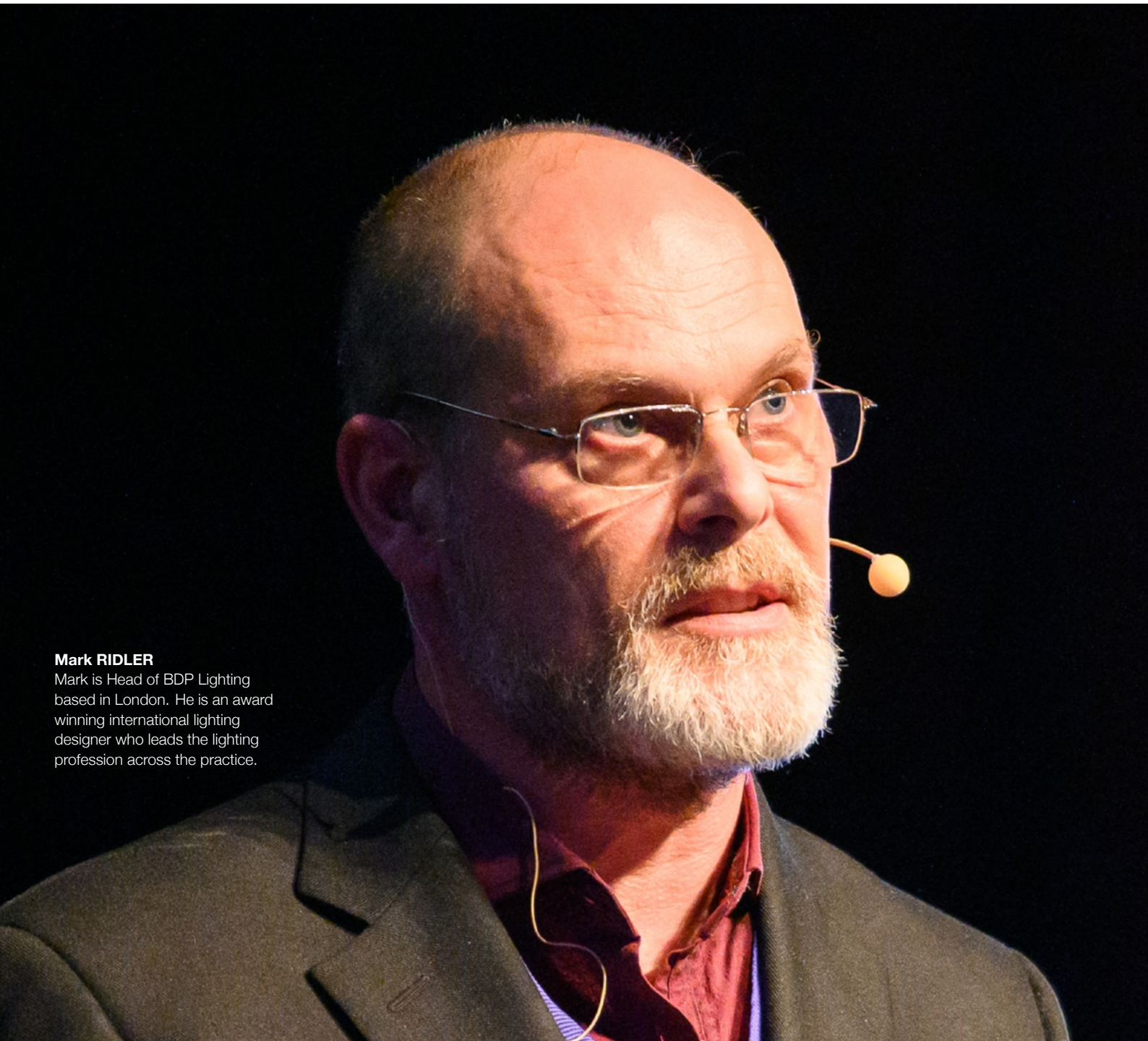
Circular Economy from the Perspective of Lighting and Project Design – Mark RIDLER, Head of Lighting at BDP (Building Design Partnership)



Mark RIDLER
Mark is Head of BDP Lighting based in London. He is an award winning international lighting designer who leads the lighting profession across the practice.

After his talk on Circular Economy at the LpS Digital conference, Mark RIDLER, a thought leader in lighting design, tendered a few groundbreaking, in depth views on some of our questions.

LED professional: Hello Mark, thank you for agreeing to this follow-up interview after your LpS Digital lecture.

Mark RIDLER: Happy to be here!

LED professional: I was hoping to start with your understanding of the circular economy in general. In other words, how does circular economy fit in with the lighting domain?

Mark RIDLER: Our research was about how lighting relates to the principle of circular economy. This has been well described by the Ellen MacArthur Foundation. The current industrial model is one where you dig stuff out of the ground, combine components, use it and then you throw it away. We're moving towards trying to recycle some of it before we throw it into landfill. However the way products are made at the moment means that at the end of their life the value of the material is pretty low. In the main, it gets crushed and a lot of value is lost. So what we need to do is move to a situation where we don't dig anymore out of the ground and at the end of life, we use that material or product again and again. When you can't use it anymore, you cannibalize it and reform it into something new, and when you can't do that anymore, that's when you recycle it. We should be looking at 100% recycling so that the material doesn't actually disappear from the use chain. It will take a lot of time and effort, and I suspect, will require a lot of thinking and collaboration to totally close that loop so there's no material leaking in and out of the system. The two drivers are biodiversity and resource poverty – and not, actually, climate change.

The biodiversity element means essentially that by throwing stuff away, we're poisoning our biosphere and it's a big problem in terms of the mass extinction event that we're experiencing at the moment. In terms of resource poverty, I don't think this one is as high up on the public agenda as it should be, but we only have decades of stuff left; not centuries or millennia – only decades. Some reports I've read say that copper will no longer be found in the ground by 2050 [1].

LED professional: Mark, you mentioned in your lecture that a major trigger comes from the suppliers. So in order to understand the requirements and needs of the entire value chain, can you explain why the trigger came from the suppliers and not the project owners?

Mark RIDLER: The circular economy is predominantly perceived as a question of manufacture. Most of the circular economy models you'll see are about products; what we make or what we do with products at the end of life. The point that I've been discovering, and that I'm trying to make, is that within lighting and within the built environment it's actually a project cycle. It's a client cycle, where the product goes into the project cycle, predominately at construction and at different points during the operational lifetime. So we can, as designers, specify products, which, in theory, can be forever reused – returned – at end of life. Although as I explained in my presentation, there are other techniques as well.

But let's just concentrate on product for the moment. If we specify that product, it's no use to man nor beast if the contractor doesn't buy it. If the contractor buys it, it's no good if the operator throws it into landfill. It's not a circular economy product. To drive that circle, you need an informed client who is willing to insist that the circular economy principles are applied to A) the project bid, B) to the design process, C) to the construction process, and then D) in use.

LED professional: And what are the advantages for the client? Why should they do that?

Mark RIDLER: They have to believe in it. It's going to become ever more important. At the moment there's quite a lot of thinking within building design about net zero. There has to be a wider recognition of embedded carbon, and not only carbon in use. To make truly informed decisions you have to take total lifetime energy in use into consideration - and that's increasingly going to drive design decisions.

To give you an example: The most important decision you make as a developer in terms of net zero is whether or not you're going to reuse a building or demolish it. So you can see that the way we approach building is going to change. And that's just step one. There are many, many steps: It's a very large

[1] https://www.visualcapitalist.com/forecast-when-well-run-out-of-each-metal/

topic. With reference to lighting – my experience is that clients already have this on their agenda. They just haven't quite worked out how to do it yet. I'm not hearing clients say "That's all well and good, but I'm not really interested" which was the situation five years ago when we were having conversations with the supplier chain about embedded carbon and recycling. They would ask "Are your clients interested in this? Are your clients driving it?" And the answer was "No". So moods change.

LED professional: You also talked about the use of daylight in your lecture. If you make a new building you can take that into account right from the start, but what are the principles you use for existing buildings?

Mark RIDLER: The irony is that buildings built before 1970 actually have really good daylight. It was only after that era, when we were able to pump fluorescent light and artificial conditioned air into buildings that people decided to go deeper and deny users the benefits of fresh air and natural daylight. So actually, what we do in terms of existing projects is to first investigate what the existing daylight condition is, and then make sure that we harness that to its maximum.

LED professional: How do you do that? Do you guide daylight into the rooms?

Mark RIDLER: No. It's more a case of studying the base conditions. For instance, we've completed two projects recently, one of which, 64 Victoria Street, is the former Westminster City Council Town Hall – a 1970's tower with excellent daylight. We didn't need to do anything to it. The façade had to be retreated and we had a play with the glass specification and glare shielding for blinds, but the essential fundamental daylight performance in that building was excellent. So we responded to it, rather than ignoring it and putting artificial lighting everywhere.

If commissioned to work on an existing building, armed with an understanding of the daylight performance, the new metrics help to do it a lot better. We can be much clearer as to where you will have daylight and where you don't need artificial lighting.

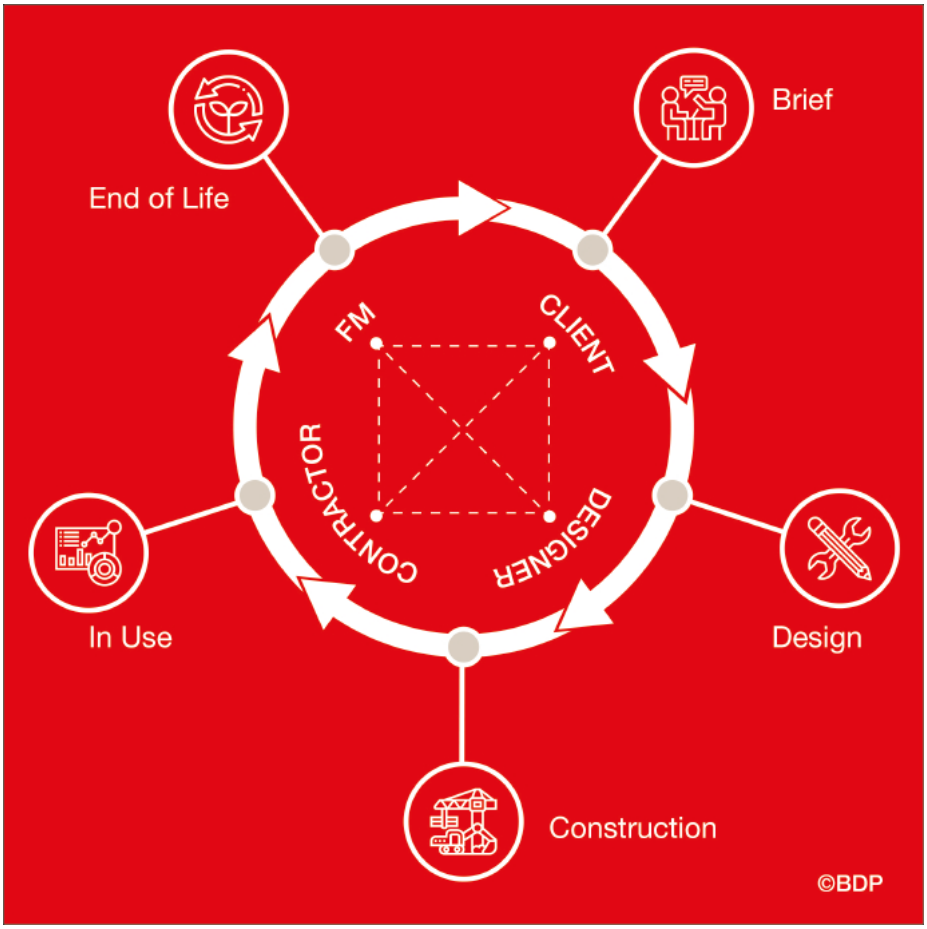


Figure 1: Circular Economy project circle chart.

LED professional: Do you use systems or light guides?

Mark RIDLER: No. I have found in the past – and maybe I differ from other designers – but whenever I've investigated, the gains have been marginal. The most fundamental relationship is (assuming a side lit space) between the ceiling height, the depth of the space and the size of the windows. Essentially, that's what it is. The next aspect is space planning and where you place the dense, human function relative to those lit spaces. We have learned that it just isn't satisfactory to try to duct daylight into spaces where it doesn't exist.

LED professional: In this context, you mentioned using the "Code Intelligence." Could you please explain that?

Mark RIDLER: It's a paraphrase. What it means is that you can interpret British standards, Euro norms code in a very blanket fashion, such as; we need 500 lx on the desks, so we will put it everywhere and people can work anywhere - the classic interpretation in a workplace environment. But that's not actually what the code says. The code says that where you are reading paper you need 500 lx, and where you're doing computer work you need 300 lx, and outside of that immediate task area you need another light level, and beyond that, you need an even lower light level. So actually, if you understand the code and apply it with intelligence, you have the opportunity to A) drive energy massively out of schemes and B) drive material out of schemes, hence, the impact on circular economy. Also, you create spaces that are not blank, uniform and industrial in feel, but ones that are actually characterful and tailored to the human activity within the space. So, it's a win, win, win situation. But if you just say "It's workplace – it's 500 lx. Here's an array of light fittings – there you go" or even worse, say "Oh, we'll make it circadian by putting everything in as tunable white" and thinking that it is somehow a solution, it's not an optimal way to proceed.

LED professional: You also mentioned some product manufacturing trends from suppliers. What exactly are they doing?

Mark RIDLER: Well, there are a lot of things they're doing. Different manufacturers are taking different approaches. I'll give you one example - a manufacturer takes old industrial fittings, repurposes them – revamps them with modern technology, rewires them, makes them safe, sells them to the market. This manufacturer then has an ongoing contractual agreement with the user, so that at the end of life, the user returns it so the manufacturer gets a discount on a new product. They refurbish it, rewire it, put the latest lamp technology in and then sell it back to market again. So it's a circular path. There are other people repatriating manufacture from abroad to the UK to minimise the length of the supply chain, reducing so-called "light miles" that a particular product would have. There's a whole lot of work generated by using recycled material rather than virgin material. There's a lot of research underway on packaging to make sure it is 100% recyclable and made from recycled material. There are interesting variations as well in how products are packaged together for a particular project. It's not only about using cardboard, it's more nuanced than that.

Other manufacturers are beginning to look at not only selling you product, as their business model, but actually, how they can service their clients' needs on site. That might be an on-site upgrade service or an on-site repair service. Rather than saying, "Okay, we'll sell you a whole suite of light fittings," they say, "Right, well, these aren't our light fittings but we can come in and refurbish them and put new guts in them." There's a whole variety of different approaches and business models currently being investigated.

LED professional: Does it go in the direction of "Light as a service"?

Mark RIDLER: That is certainly talked about a lot, although personally, I think that very few people will do it at the moment. It might have a place in super huge projects like airports or industrial facilities, but for most projects it restricts you to a single source of supply. Then you have to ask who is actually going to do the design, will you lose the opportunity to use an independent design consultant with all the product agnosticism that they bring to projects? I'm quite suspicious about it as a model. We did investigate it for the refurbishment of part of our own London office and it generated almost no value. Essentially, it's a finance model; a way of avoiding capital expenditure and putting into operational expenditure. Then it becomes a debate about interest rates and whether or not it's good value. It doesn't in itself ensure that the manufacturer will take back, recycle, reuse or repurpose it. Lighting as a service could quite easily lease you a product, only to take it back and throw it into landfill at the end. As long as the financial model accounts for that, there's no reason why it won't happen. Take, for instance, mobile phones: a classic example of a lease model; the phone company doesn't take the product back at the end, they bin it. Another one is cars: you're encouraged to change your vehicle every three years which is the least circular economy thing you should be doing. You should keep your car for many, many years, but the leasing model doesn't encourage you to do that. So I'm not convinced that lighting as a service is a massive CE driver in the lighting industry.

LED professional: Another innovation we have been seeing lately from several companies are 3D printing components.

Mark RIDLER: I'm really interested in that. I'm paying close attention to whether it's genuinely reducing the amount of material entering and exiting the product life cycle. It's very compelling, I'm fascinated by it. If the promise is that you can make a light fitting and and then take it back at the end of life, shred it, and put it back into the 3D printer and make another product – and you can do that bespoke to project so you reduce massive transport chains – wow, that's really exciting.

LED professional: In your lecture you showed some cost tables and mentioned that you still have to do some evaluations due to circular economy designs. In the end, though, how does it influence the return on investment for a complete project?

Mark RIDLER: We were working on a confidential project over the summer that unfortunately went on hold – but the client took a circular economy approach. We asked the quantity surveyor on whether CE was more expensive. His take on it was that some elements are a little bit more expensive, but you gain by reducing the amount of material that's coming in. So my sense is that it's not significantly more expensive , but I don't currently have a project that I can work all the way through to prove that. What's more important is to stop evaluating the capital costs and the operational cost of a project and look at it as a whole. For our clients, that will prove quite diffi-

Figure 2: Bright Building Manchester Science Park © BDP, Nick Caville. The design satisfied many of the BDP Circular Economy principles. The main ones were "Building in Layers" and "Design for Disassembly" as all the lighting used surface mounting techniques avoiding recessing and integration. Secondary factors were "Designing out Waste" as the design was highly optimized and "Design for Adaptability" – the surface mounted principle allows for spaces to be easily reconfigured by swapping out luminaires to create new environments when and as needed.

cult, because normally their budgets are very distinct. The big driver to encourage them to wrap them together will be net zero.

To give you an example – we're working on a hospital and the brief says it has to be net zero. We say, "Fine, but can you afford that in operation?" They will ask if they have to make that evaluation and the answer is "Yes, you do." That's the point when evaluation of total cost of ownership will drive the design. Only when this happens will we be able to answer the question of whether circular economy is more expensive or not.

I would say that part of the reason it's really important is the cost of not doing it – we don't put a price on the environmental impact. We don't cost for flooding. We don't cost for the extinction of a species. We don't cost for the demand on health systems. Some argue that the current pandemic is in part due to the loss of biodiversity. We don't cost for that. So we are going to have to become more sophisticated in our costing mechanisms. Resource depletion is increasingly going to drive this. If you run out of stuff, you've only got the stuff you already have. It will cease to be a question of "Can we afford it?" and become "We have to do it: how do we make it affordable?"

One of the things that is very exciting about lighting is its particular position at the forefront of the debate. As a community, lighting can be nimble and adaptable. Some of the problems have massive impacts on bigger issues, like how much concrete to use or how to develop steel, the whole question about density and reuse of buildings etc. We're a little part of the whole construction edifice but when the debate happens in our realm, we have a very important advocacy role for the rest of the building industry. This makes it really exciting, and highlights our role to clients. It increases the value placed upon lighting, not only in terms of this narrow part of the debate, but more generally – they introduce questions like "Is lighting only about engineering quantities of light, or is it about other things? Is it about psychology? Is it about wellness? Is it about the wider sustainability debate?" It has the potential to drive a greater, more sophisticated appreciation of what lighting can provide, and this is a very hopeful and exciting place to be.

LED professional: Straying away a little from that topic, and coming back to an important topic for us is the question of human centric lighting: Putting aside the 500 lux standard rule, they say that good human centric lighting needs up to 2000 lux in certain conditions, which, of course, increases consumption. There is a project where they increased background illuminance levels beyond the standards just for a desk, and this contradicts lower energy consumption. What is your view on this?

Mark RIDLER: I have a contrary view about this. We've been applying circadian lighting for many, many years and I don't think it's about light intensity and color temperature, those are only two components of a very complex situation. In the workplace, where people have the freedom to enter and exit the office, the employer has such a low level of control over an individual's total circadian environment that increasing the burden on our biosphere is not morally the right thing to do. There isn't yet a wellness standard or an understanding of what dose of light we require to achieve what we want to achieve, so we're shooting blind. We think it might be this, or we think it might be that. There are certain things that we do know – that light has a physiological impact and we know what the most active frequencies are. But we still don't know how much and for how long. And we still don't know the profile. What we do know is that we evolved for tens of thousands of years in daylight and that's what we need. So access to daylight is the main objective in terms of wellness. That's daylight in buildings, but it's also making sure that people have time to get out of their buildings into daylight. Your journey to work, how you spend your lunch break, your journey home and how dark your living space is at sleeping time is as important, if not more important than how many lux you put into an office. Whether or not you sit by a window, and you're allowed to sit by the window, is more important than how many thousands of lux you put into the space away from the window. For me, that is much more important.

On the other hand, you still have to design artificial lighting systems – what do you do? We have been taking a very layered approach for years. It's about psychology and how you blend that artificial lighting with the daylight environment that you can see. It's not only about the amount of light that's hitting the task and face, it's also what you can see and how that changes, and crucially, how bright the ceiling is. It's also about the position in the room where the light comes from. When you go warm at the beginning and the end of the day, it should come from a low position – like the sun low in the sky - not from the ceiling. Then task illumination must be considered – whether it's desk mounted or floor mounted, how the ceiling and walls are illuminated and crucially, how people can control light within the space; this way the psychology behind the light environment matches the psychological environment.

What I really, passionately believe is that it is NOT about an array of downlights pumping out 2000 lux that change from warm to cold throughout the day and then back to warm again. It's absolutely not about that: and we cannot afford to do that in terms of carbon.

LED professional: I'd like to ask a question about demountable opportunities – taking luminaires to the next project. What are the solutions?

Mark RIDLER: It's very much a work in progress for us. I've spent my entire career trying to hide light: light without light fittings. LEDs made everything smaller, cold to the touch and with less electricity, which made integration so much easier. That approach caused an explosion in creative thinking and generated some fantastic schemes and really beautiful spaces, but design moves on and maybe we need to think in a different way now. There's still a way to integrate light fittings. Our architects have not been entirely averse to the aesthetic implications of the circular economy potentially driving the design, so I think it's something we, as a design community, need to explore. I don't necessarily think it's a bad thing, but it will drive a different visual approach and that's quite exciting.

LED professional: Do you think the systems need to adapt? Will it be going more in the direction of panels?

Mark RIDLER: Yes, I do think they'll need to adapt but I don't have all the answers. These will evolve as we start bringing our thinking to project specifics, we'll work it out as we go along.

LED professional: You mentioned the use of facility management in your presentation on the circular economy. What is the role of the facility manager in this kind of lighting design?

Mark RIDLER: Their role is as important as anybody else's within that circle. Designers traditionally have very little visibility or contact with operational staff. I think that's a weakness and it needs to change. They need to enter into the design process. If they are responsible for maintaining these systems and recycling and reusing them, we need to listen and respect their opinion so that they have the opportunity to influence design decisions.

LED professional: So that's not the case right now?

Mark RIDLER: No. It's a massive divide between capital expenditure and operational expenditure and the two rarely meet, even within single client bodies. It's more of a challenge for our clients than for us, to be honest, but there are all sorts of ways in which we can help. Specifying equipment that is repairable would be a good start.

LED professional: To finish up, can you give us an idea of where you think the future will take you? You have this ongoing circular economy research project, do you think circular economy will be part of all your projects, moving forward?

Mark RIDLER: Not every project, but at the beginning of each new commission we'll ask the client the question. There's a testing question which is, "If you could buy second hand equipment for the project that we're engaged on right now, would you do it?" If the answer is "No," it's not a circular economy project and we would just approach it in the conventional fashion. But if the answer is, "Well, maybe," then we're in a position to start thinking about it. As I've said, of all the conversations I've had with our clients about this, certainly a large percentage have been interested and engaged. It's more likely the bigger clients that have more control, 'owner occupiers' rather than multi-tenanted buildings, but I think that it will disseminate throughout.

The other thing I'm really excited about is collaboration. This has to be throughout all aspects of the industry: Education, suppliers, lighting designers and other designers, contractors and clients. Also within each of those classes; those consultants are going to meet up with other consultants to come up with a consensus as to what we should be doing and how it should be done. I'm also extremely excited about how fast that is moving. For instance, I'm part of a new initiative just launched called the Green Light Alliance[2], which is essentially a forum for collaboration with a short-term aim of achieving a design check-list that could be shared widely. The Society of Light and Lighting within the UK is beginning to formulate that and we're also talking to Lighting is Good and other people who are creating these types of evaluation processes. We want to harmonize this thinking rather than see different, separate, discrete and uncoordinated interventions. Harmonization would be really powerful and useful, it will help people outside the lighting industry to understand our role. I have no real interest in developing a BDP Circular Economy approach specific to our company because its impact will be very small. If, however, there is a consensus within the whole lighting community and they say, "Yes, this is what we should be doing", that will have massive impact.

So, in answer to your question: the two things we are moving towards are to talk to clients and win more projects which actually domonstrate the principles and develop our ideas and the other is to encourage collaboration with the wider design community to build consensus as to what it is we should be doing - and then doing it.

LED professional: Mark, that was an excellent conclusion. Thank you so much for taking the time to talk to us.

Mark RIDLER: Thank you very much for the opportunity. ■

[2] https://www.greenlight-alliance.com/

Figure 3: The LpS Digital conference lecture by Mark RIDLER can be viewed on www.LpS-Digital.global

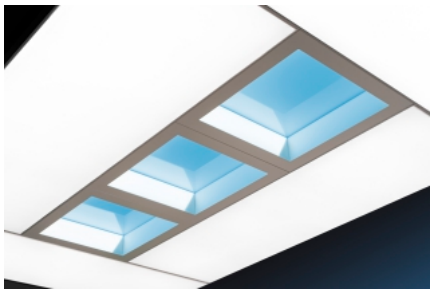
About Mark RIDLER

Mark has over 35 years' experience and is a Fellow of the Royal Society of Arts (FRSA). After designing over 100 shows, he became an associate at MBLD in 1998 and joined BDP in 2003. Mark believes that collaboration is essential for great design and has recruited a vibrant team from varied backgrounds, including product designers, engineers, theatre designers and architects, effectively forging them into a winning force in international lighting design. Human interaction with architecture through the medium of light is central to his philosophy and practice.

His projects are varied, covering commercial, public realm, leisure, retail, art and art galleries, transport and daylight design. Mark has won many international awards including an Award of Merit for Princesshay, Exeter, and the IALD Award of Excellence for Finsbury Avenue Square, London. Mark was named Lighting Designer of the Year at the Lighting Design Awards in 2014 and was honoured with a Special Recognition Award from the Institute of Lighting Professionals in 2016. Mark was Vice President, Architectural for the Institution of Lighting Professionals (ILP) and its first Chartered Lighting Designer.

Bringing the Benefits of Natural Light Indoors

For thousands of years people have lived in sync with nature, with the rising and setting of the sun and changing seasons and weather. Daylight is something we often take for granted, but it is as fundamental to life as food, water and air. When we lack any of these three fundamentals, we notice an immediate effect on our bodies. Light has a less direct but equally strong impact.



Nature as a Source of Inspiration to Rethink Lighting

Natural light and darkness cycles are essential to sync our internal body clock with the outside world. Robust and synchronised circadian rhythms are at the core of good health, quality sleep and wellbeing [1]. Yet the Industrial Age, and the invention of artificial lighting, resulted in an estrangement from natural day and night rhythms. Today's way of living and working means people spend most of their time indoors, with the lockdown measures over the last year heightening this reality.

"Humans have a fundamental need, not just a desire, to connect to nature."

CRISTINA TANASE

Although individual preferences differ, there is one thing most people have in common: a universal and positive reaction to nature and natural elements. People simply enjoy being outside in nature. Immersion in nature can be stimulating and energizing but equally calming and relaxing. It has a restorative effect on our health and wellbeing. The positive impact of a walk in the forest, taking in the majestic view of a mountain or an energizing day at the beach are universally recognized. Humans have a fundamental need, not just a desire, to connect to nature. There is an increasing amount of research echoing nature's profound effect on human health [2]. This is the basis of Biophilic Design, which uses elements of nature and natural analogues in interior spaces to make people feel happy and healthy.

Light for Health and Wellbeing

Light enables us to see the world around us. Traditionally, indoor lighting was mainly driven by visual requirements. It is only relatively recently that a novel photoreceptor type in the inner retina was discovered, fundamentally challenging this traditional view [3]. It is known now that, in addition to stimulating the visual system, light incident on the retina stimulates other biological functions - also referred to as non-visual responses (**Figure 1**). Light regulates our day and night rhythm and helps us to function better. In addition, light creates atmosphere and sets our mood, it evokes specific emotions and helps us to feel better.

Light to See Better

A good lighting design supports the illumination of objects in central vision, with balanced lighting in the peripheral vision providing optimal eye comfort. Light that supports people to see better creates exactly the right balance between clarity and comfort, while taking into account the specific user needs in the environment.

"Light has visual, biological and emotional benefits – helping people to see, function and feel better."

BIANCA VAN DER ZANDE

One challenge which is present today in society and implicitly in workplaces is aging. The eye already starts to deteriorate around age 45 **[4]** which means that approximately one third of the potential working population is already facing reduced vision. Research conducted by Signify confirms this situation and found that visual acuity and perceived comfort can be improved by increasing light levels **[5]**. This is relevant since visual fatigue and discomfort have been reported to relate to ergonomic complaints such as pain in neck and shoulder **[6,7]**. Other research indicates that users across age groups tend to prefer higher light levels for more demanding tasks **[8,9]**, while lower levels are often experienced as more relaxing for the eyes **[10]**.

The right light depends on the task at hand but it is clear that a conducive working environment, and comfortable vision, relies on well-balanced lighting design for a space.

Light to Function Better

Light also enables people to function better. To be active during the day and rest well at night, our body needs a stable predictive cycle that is synchronized to the natural day rhythm. Preferably in the morning, people need a boost in energy and focus, to function effectively during the day. Morning light plays a significant role in triggering this energy boost and bright light during the day enhances circadian rhythm, regulating the sleep-wake cycle. Traditional workplace design focusses on providing light that is good for vision and in line with the norms in indoor spaces: 300–500 lx. However, natural daylight levels are much above these levels, ranging from 10 000–100 000 lx. Exposure to higher indoor illuminance levels of at least 1000 lx, has been proven to increase alertness and performance **[11]**.

Next to light quantity expressed in intensity, the light quality expressed in spectral distribution plays an important role for people's health and wellbeing. Specifically, light enriched in the 450–530 nm range is proven to be an effective and powerful light signal to regulate the timing, robustness and rhythmicity of the body clock **[12,13,14]**, thus directly impacting the ability to stay alert and focused (for work or learning) during the day or to fall (or remain) asleep at night. The spectral sensitivity of humans for light in the range of 450–530 nm has been related to specific intrinsically photosensitive ganglion cells in the retina and is also referred to as melanopic light. However, the effectiveness of light to regulate the body clock not only depends on intensity and the spectral composition of light. Also exposure duration, prior light history, timing of the light exposure, as well as individual sensitivity to light play a significant role.

"Intense light can improve feelings of alertness and vitality, as well as objective performance."

SMOLDERS ET AL. [11]

Light to Feel Better

In addition to the visual and biological benefits of light, the third crucial element is the emotional benefit of natural light to make people feel better. Positive effects of light on behavior, mood, satisfaction, and com-

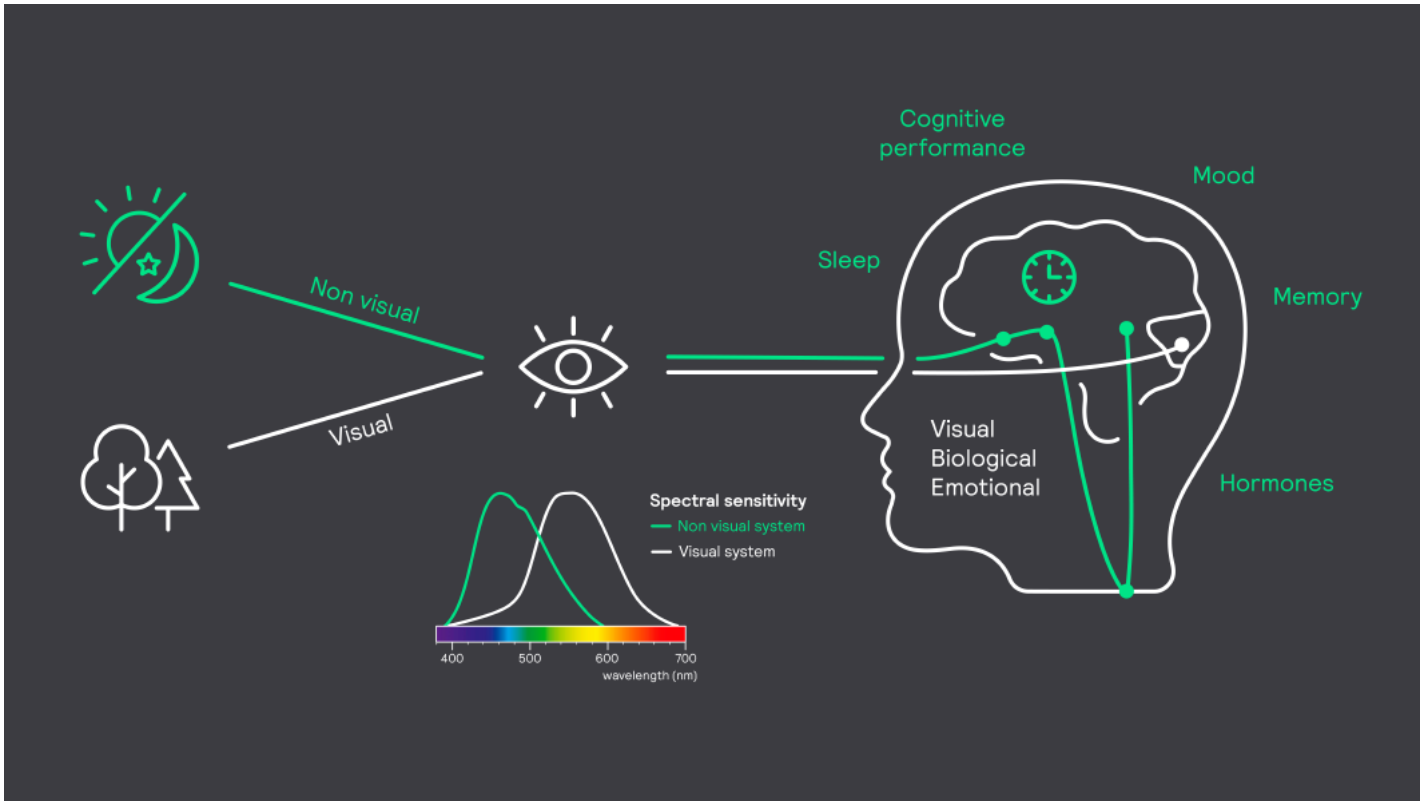


Figure 1: Light enables people to see better, function better, and feel better.

fort have been intensively studied in the past years [15,16]. Especially the concept of Biophilia, the practice of incorporating nature and natural elements into the built environment, is a strong contributor to this. Biophilic Design has been proven to measurably reduce stress, enhance cognitive function and creativity, boost productivity and increase wellbeing [2]. Specifically, access to natural light and views of the outdoors has been identified as the number one valued attribute of the workplace environment [17]. In offices with natural elements, such as plants and sunlight, 15% higher level of wellbeing, 6% higher level of productivity and 15% higher level of creativity has been reported [18]. Other research shows that bright light exposure, via artificial skylights, generates psychological comfort, increased productivity, and assumed health [19,20].

Since the natural light benefits of seeing better, functioning better and feeling better are interdependent, efforts to influence one relates to always influencing the other two as well. As a consequence, designing spaces must balance these three elements, with the thought in mind to satisfy the needs and desires of the people using the space, while addressing the regulations and requirements for the space.

Figure 2: The NatureConnect lighting solution combines various LED luminaires. **Daylight** – Mimics the daily rythm of the sun to help people stay active during the day and rest well at night. **Skylight** – Provides a view to the sky to create a feeling of spaciousness and connection to nature. **Lightscape** – Applies natural colors and dynamics on the wall for a fully immersive experience.

Figure 3: The system uses advanced content, smart sensors, and intuitive control to create tailored, natural lighting scenes. During the day, the system will automatically follow the rhythm of the sun. In addition users can choose between different relevant lighting scenes such as energize, relax, or present.

How to Bring the Benefits of Natural Light Indoors

Signify uses innovation to change the way lighting is created and implemented in the built environment. As the world leader in lighting, Signify harnesses proven expertise to deliver a wide range of high-quality lighting solutions that building occupants, facility managers, and installers can use to create workspaces that go beyond being simply fit for purpose.

"To rethink lighting for professional spaces we focus on the qualities of nature and natural light that we miss when we spend so much time indoors."

INGE VAN DE WOUW

NatureConnect by Signify **[21]** aims to bring the benefits of natural light back into our daily lives, at the spaces where we spend most of our time. It is built on the visual, biological and emotional benefits of natural light. Guided by Biophilic Design principles combined with application knowledge, and innovative LED and connected technologies, NatureConnect creates rich and meaningful lighting solutions for comfortable, engaging and attractive indoor environments that support wellbeing.

The NatureConnect system contains different lighting elements that all have their own role to play and collectively create a natural lighting experience. It provides the right light at the right moment during the day, by taking all relevant factors into consideration (**Figure 2**). The system uses advanced content, smart sensors, and intuitive control to create tailored, natural lighting scenes. During the day, the system will automatically follow the rhythm of the sun. With the intuitive wireless user interface, the end-user can switch from the circadian rhythm to a lighting scene best suited for the activity in the room. Users can choose between different lighting scenes such as energize, relax, or present, or leave the lighting to follow the natural rhythm continuously throughout the day (**Figure 3**). Combined results of quantitative end-user surveys at different customer sites indicated that 80% of the office workers agree that NatureConnect lighting is more pleasant. Moreover, 80% confirmed that the lighting feels more like daylight.

The system is modular and versatile, adapting to different spaces and needs. It is a perfect fit for any professional indoor environment, where people spend long hours indoors or where people lack sufficient access to daylight. Offices, hospitality, conference centers or care institutions can all benefit. It provides increased value of space and improved user experience – all by using the power of light (**Figure 4**).

Let Us Collectively Rethink Lighting to Support Health and Wellbeing

Signify is committed to demonstrate the major role our built environment has on our wellbeing and quality of life and is pleased to showcase market ready solutions like NatureConnect, that both inspire innovations and can create better lifestyles for people worldwide.

Figure 4: Van Rennes in the Netherlands was one of the first NatureConnect installations.

The COVID-19 pandemic has put health and wellbeing at the forefront and reminded us that, in a building, nothing is as important as its users. There is now an opportunity to ensure workplaces welcome users back into healthy environments where they feel and perform at their best. Knowing that we spend 90% of our time indoors, it is up to all of us to make our indoor spaces happy and energizing places. Organisations that already live by these principles have been shown to make a difference, not only for their people, but to their business too.

Together, we can collectively rethink lighting for this new era and transition towards indoor environments that intrinsically support health and wellbeing. ■

More About NatureConnect?
Please visit the website to discover more and get in touch:
www.signify.com/natureconnect

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Cristina has a background in physics and PhD degree in molecular electronics from University of Groningen, The Netherlands. Following her studies, she worked in different functions in Philips and currently Signify, becoming an all-round professional with passion on bringing innovation to market. Cristina built experience in several leadership roles in businesses at different maturity levels, from Research and Development to start-ups and well-established business environments. As General Manager of NatureConnect by Signify, she takes a leading role to unlock through innovations the extraordinary potential of light for brighter lives and a better world. NatureConnect by Signify creates rich and meaningful lighting solutions by bringing the benefits of natural light in indoor spaces to create comfortable, engaging and attractive environments.

AUTHOR: Inge van de WOUW
Inge has a background in Industrial Design, from Delft University of Technology, the Netherlands. As a designer she is passionate about bringing meaningful innovations to market. With over 10 years of expertise in Light for Health & Wellbeing across different roles, she has been at the forefront of many innovations and new business start-ups that use the power of light to make people see better, function better and feel better. Currently she is working for NatureConnect as Segment and Marketing Manager. NatureConnect by Signify creates rich and meaningful lighting solutions by bringing the benefits of natural light indoors. It reconnects us with the constant cycles and variations of nature for comfortable, engaging and attractive indoor environments.

AUTHOR: Bianca van der ZANDE, PhD
Bianca is a Senior Scientist at Signify Research. She is motivated to improve people's life through developing lighting solutions designed to bring the benefits of natural daytime light inside. Her current work entails (1) orchestrating open innovation programs with several universities to unlock the potential of natural light to health and well-being and (2) to defining meaningful circular economy ready lightings solutions. Bianca has over 10 years of experience in the area of lighting research. She has translated scientific knowledge about the visual, biological and emotional effects of light into Signify's lighting systems for a broad range of application areas including nursing homes, schools, offices and homes. Her work includes early validation of the ideas and solutions with consumers as well as validation of the product in the field with professional lighting customers. Bianca holds a doctorate in Physical and Colloid Chemistry from the University of Utrecht in The Netherlands.

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TYPE	CRI	CCT	EFFICACY
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ipRGC Sensitivity Optimized LED Spectrum and its Application in Color Temperature Tunable Solutions

Currently, in HCL applications, several important technical characteristics are considered. In addition to the ipRGC stimulation topic, there is Color Temperature Tunability (CTT). These two characteristics of a lighting solution are correlated to one another as they both arise from man's exposure to daylight. Nichia has created an almost pure cyan LED with a spectral emission characteristic to stimulate the ipRGCs optimally. Menno SCHAKEL, Sadakazu WAKUI, Kenji ASAI, Shigeharu YAMAUCHI, and Xavier DENIS explore their findings in this LpS Digital conference paper.

The concept behind the research and development of the Vitasolis™ technology was to support the demand of the general lighting industries for ipRGC[3] stimulating lighting solutions. The feedback and acceptance received from the market about this technology are very positive, but eventually one question always comes up; what about a tunable version? Human ipRGCs are stimulated in the morning when the sun is bright, and the sky is blue. Morning daylight has a higher content of lower wavelength (cyan) light which stimulates the cells. For the given time, the daylight also has a high Correlated Color Temperature (CCT), generally in the range of 5500–5800 K. During the afternoon, the color temperature of daylight slowly changes until it reaches around 2700 K at sunset when it becomes a warm yellow, almost reddish light, with low CCTs. This low color temperature light falls mostly outside the sensitive wavelength range of the ipRGCs. ipRGC stimulation and color temperature of natural lighting are two sides of the same coin, the spectral power distribution of the light is ultimately what determines these two characteristics. As HCL solutions try to mimic daylight, the request for a tunable ipRGC stimulated solution is only a logical conclusion. By continuing the development of the SAE ($Sr_4Al_{14}O_{25}:Eu^{2+}$) phosphor responsible for the emission in the cyan region.

[3]Intrinsically photosensitive retinal ganglion cells

Introduction

Circadian lighting is an HCL concept growing in acceptance by the lighting industry. The existence of a human circadian rhythm is nothing new, and lighting somehow affecting this process has also been known intuitively for many years. However, when a paper was published (Lucas et al., 2014) [1] on the newly discovered effects of light on the intrinsically photosensitive retinal ganglion cells (ipRGC), there was suddenly a way to quantify these effects. In general, the term circadian rhythm refers to any biological sleep-wake cycle with a period of roughly 24 hours. In this paper when the term circadian rhythm is used, it is specifically referring to the human circadian rhythm.

Circadian Lighting

Several spectral sensitivity curves have been published which, when combined with the spectral distribution of a light, can be used to calculate the equivalent α-opic quantities, like melanopic illuminance. It is important to realise the distinction between melanopic lux as defined by Enezi et al. (2011) [2] and melanopic-lux defined by Lucas et al. (2014) [1]. Due to a difference in scaling of the spectral distribution, there is also a scaling factor difference between the two quantities. A similar situation occurs with the WELL building standard (International WELL Building Institute, n.d.) [3] melanopic light calculation of Equivalent Melanopic Lux (EML) and Melanopic Ratio (MR). A scaling factor, referred to as the equal energy constant, is introduced as the sensitivity curve for melanopic light is not weighted against the maximum of spectral luminous efficacy ($K_m \approx 683$ lm/W) (CIE, 2014) [4].

Correct use of terminology is extremely important, as there are already two various usages of the term melanopic lux mentioned above. It is also good to recognize the difference between a unit and a quantity. A quantity specifies the 'what', like length, or luminous intensity.
A unit specifies in what denomination a quantity is measured (e.g. meters for length, or candela for luminous intensity). Lux, melanopic lux and equivalent melanopic lux are all units for different quantities, respectively illuminance, melanopic illuminance and melanopic equivalent illuminance.

Specifying the melanopic lux of a source is like specifying the meters of a road; it is incorrect. What should be specified is the melanopic illuminance of a source in melanopic lux, like specifying the width of a road in meters.

Combining these details brings the following equations together. From the WELL building standard (IWBI, n.d.),

$$MR = \frac{\sum MC_\lambda \cdot E_{v,\lambda}}{\sum VC_\lambda \cdot E_{v,\lambda}} \cdot \frac{K_Z}{K_M} \quad (1)$$

where

- MR is the melanopic ratio,
- MC_λ is the melanopic curve (specified per 5 nm),
- VC_λ is the visual curve (specified per 5 nm),
- $E_{v,\lambda}$ is the spectral irradiance of the source in question (specified per 5 nm; the unit is actually not relevant as this is divided out with the term being in both the numerator and denominator),
- K_M is the maximum photopic luminous efficacy,
- K_Z is the maximum melanopic luminous efficacy,
- $\frac{K_Z}{K_M}$ is approximately 1.218 as specified in the WELL standard (IWBI, n.d.).

The MR can also be calculated using the equivalent melanopic illuminance as specified by Lucas et al. (2014) as follows,

$$MR = \frac{E_{Z,v}}{E_v} = \frac{E_Z \cdot K_Z}{E_v} \quad (2)$$

where

- E_v is the (photopic) illuminance of the source,
- $E_{Z,v}$ is the equivalent melanopic illuminance of the source in question (stated in the same units as the photopic illuminance – a quantity specified by Lucas et al. (2014)).

For **Equation (1)** and **Equation (2)** it is interesting to note that the calculations can also be done with other photopic quantities. For **Equation (1)**, the spectral irradiance ($E_{v,\lambda}$), can be substituted by the spectral luminous flux ($\Phi_{v,\lambda}$) and the calculation remains valid, as the units are cancelled due to the term being in both the numerator as well as the denominator. In **Equation (2)**, the illuminances E_Z and E_V can be replaced by equivalent melanopic flux (Φ_Z) and luminous flux (Φ_V) respectively.

The benefit of the melanopic ratio is that once the ratio has been calculated for a certain spectrum, the melanopic behavior can be calculated based on only knowing the photopic behavior and the MR. Knowledge of the MR of a source eliminates the need to have a full spectral characterization of a source and has certainly helped the industry in accepting circadian lighting and making comparison of light sources easier. Nevertheless, using a single quantity as a quantifier for melanopic performance of a light source has its risks, just like comparing light sources only purely on luminous flux. The MR is an indicator of the ratio between photopic and melanopic performances of a spectral power distribution and is no indication of the amount of melanopic active photons.

Determining the effect of melanopic light and stimulation of the ipRGCs requires knowing the absolute amount of melanopic active photons and therefore the MR needs to be multiplied with an absolute quantity as evident from **Equation (2)**. When luminous flux is multiplied with the MR, the resulting quantity is equivalent melanopic flux.

From **Table 1**, comparing source 1, having a luminous flux of 100 lm and an MR of 1, with source 2, having a luminous flux of 200 lm and an MR value of 0.5, the equivalent melanopic flux for both is 100 lm and hence the melanopic effect for both is the same. The second source appears brighter, as it has twice the amount of luminous flux, but the melanopic effect will be the same.

Light Source	Luminous flux (lm)	MR	Equivalent melanopic flux (lm)
1	100	1	100
2	200	0.5	100
3	5	20	100

Table 1: Values for different lighting properties of three different example light sources

With the extreme case of source 3, having an MR value of 20 and a luminous flux of 5 lm, the melanopic performance is still the same as the other two sources, even though source 3 appears even less bright. Source 3 could be a blue or cyan source and therefore not even suited for general lighting purposes. The claim that source 2 is better than source 1, or even that source 3 has the best melanopic performance, just because it has the highest MR value, is clearly not valid.

The example above makes clear that MR as a quantifier for melanopic performance of a light source is not valid and that a high MR light source is by definition not better than a lower MR light source. Sometimes it seems easier to compare sources by evaluating only one quantity, but if a comparison on multiple quantities cannot be avoided, it is imperative to select the right single quantity. If the intention is to evaluate the melanopic performance of light sources, it is better to compare the equivalent melanopic flux (Φ_Z) or the melanopic efficacy of the source (η_Z), where the melanopic efficacy is similar to luminous efficacy, with P_{elec} as the power consumed by the source in W, but with the luminous of the source in the numerator substituted by the equivalent melanopic flux,

$$\eta_Z = \frac{\Phi_Z}{P_{elec}}. \quad (3)$$

Demonstration is made in the WELL building standard (IWBI, n.d.), as the requirements in the standard do not ask for a minimum value of MR, but for a minimum level of equivalent melanopic illuminance. Other than the requirement on the circadian lighting to consider, there are still also the requirements for visual lighting. A balance between circadian lighting and visual lighting is necessary. MR was only ever meant to be a tool to calculate melanopic performance of light sources when limited information about the source is known. It was never intended to be used as a comparison of actual performance and should not be regarded as such.

The International Commission on Illumination (CIE) has defined a system for the metrology of optical radiation for ipRGC-influenced responses to light. In the standard CIE S 026 (CIE, 2018), α-opic irradiance, α-opic efficacy of luminous radiation (α-opic ELR) and α-opic equivalent daylight illuminance (α-opic EDI) are defined. All the terms refer to α-opic, which refers to the different ipRGC sensitivities, with the subscript mel used for the melanopic quantities.

The main difference between the CIE system and the previously mentioned system introduced by Lucas et al. (2014) is the reference spectrum. The CIE system uses the D65 daylight standard as the reference, Lucas et al. (2014) uses the equal energy spectrum (Illuminant E) as a reference spectrum. The melanopic daylight (D65) efficacy ratio (melanopic DER or $\gamma_{mel,v}^{D65}$), is defined in the CIE system as the analogue to the MR and both can be converted from one into the other. **Equation (2)** shows this relation,

$$\frac{MR}{\gamma_{mel,v}^{D65}} = K_{mel,v}^{D65} \cdot K_Z \approx 1.104 \quad (4)$$

with $\gamma_{mel,v}^{D65}$ being the melanopic efficacy of luminous radiation of the D65 daylight standard (1.3262 mW/lm) and K_Z as defined in **Equation (1)**.

Tunable Circadian Lighting

It is important to not always be exposed to a high melanopic illuminance. The benefit of melanopic light is that it suppresses the production of the hormone melatonin. This hormone is, in large part, responsible for the regulation of our sleep-wake cycle and is the indicator for our body to fall asleep. Being exposed to melanopic light keeps us awake, which is the positive aspect of melanopic light in the morning and early afternoon, but in the late afternoon and during the evening, exposure to melanopic light should be minimized as much as possible. Melanopic light has been shown (CIE, 2019) **[6]** to disturb the sleep cycle, for instance by severely delaying the start of the cycle.

In the current general lighting market, there are several solutions for increased melanopic light products. More and more LEDs are appearing on the market with increased melanopic performance, but there is no inherent possibility to reduce the amount of melanopic light for use in the evening, other than lowering the total amount of light. Current tunable solutions use existing melanopic enhanced LEDs and conventional LEDs together to create a tunable source. The disadvantage is that the melanopic enhanced LEDs still emits light outside the melanopic sensitive wavelength range and the conventional LEDs emits light inside the melanopic sensitive wavelength range; the melanopic light output of the solution cannot be independently controlled by just the melanopic enhanced LED.

An ipRGC CTT can be assumed to have two functions when it comes to circadian lighting design; high melanopic light output in the morning, low melanopic out when it is not needed, in the evening. By separating this dual functionality in two LEDs, it is possible to design an actual circadian tunable light source.

The *Nichia Cyan* LED, a source with an ipRGC sensitivity optimized spectrum, fulfils exactly the requirement of high melanopic output, without emission in the rest of the spectrum. Combined with a Color Rendering Index (CRI) 80 2700 K LED, an LED with very little to no light in the melanopic sensitive wavelength range, a solution for independent control of functionality is introduced. The combination of these two LED spectra will be referred to in this publication as *Nichia Tune*.

The phosphor called SAE, which was already used as the basis for the first Vitasolis™ LED, has been further developed. When excited with a standard InGAN blue chip this phosphor produces an almost pure cyan emission spectrum as shown in **Figure 1**. This latest development in LEDs has the advantage of having negligible emission at wavelengths longer than 600 nm, therefore the MR value of the *Nichia Cyan* LED with SAE phosphor is inherently high at a value of 2.8.

It should be clear that the new Cyan LED by itself does not generate white light as that was not the purpose behind the design of this LED. When mixing the cyan light with the warmer CCT light of the 2700 K source, the combined light can achieve colorpoints between 2700 K and 6500 K. The

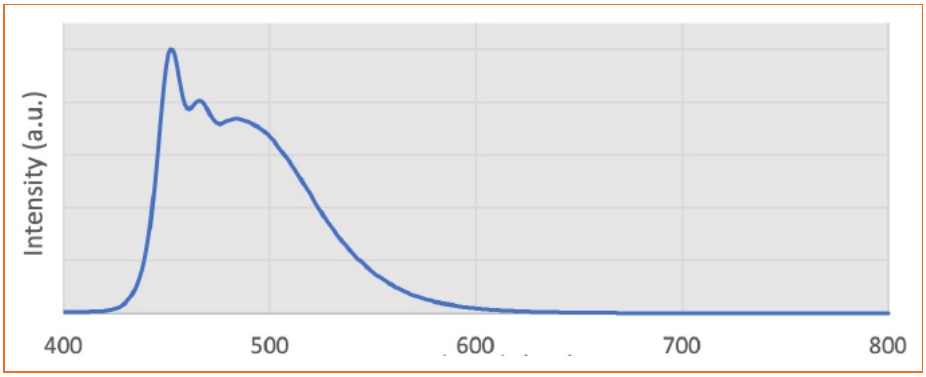

Figure 1: *Nichia Cyan* spectrum, excited SAE phosphor by blue chip.

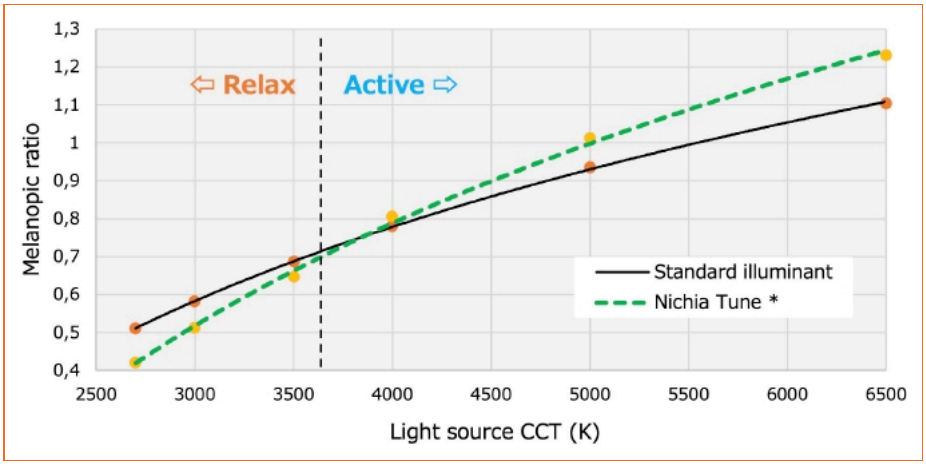

Figure 2: Comparison of MR for *Nichia Tune* and the standard illuminant of the same CCT. *Simulated data, not measured performance.

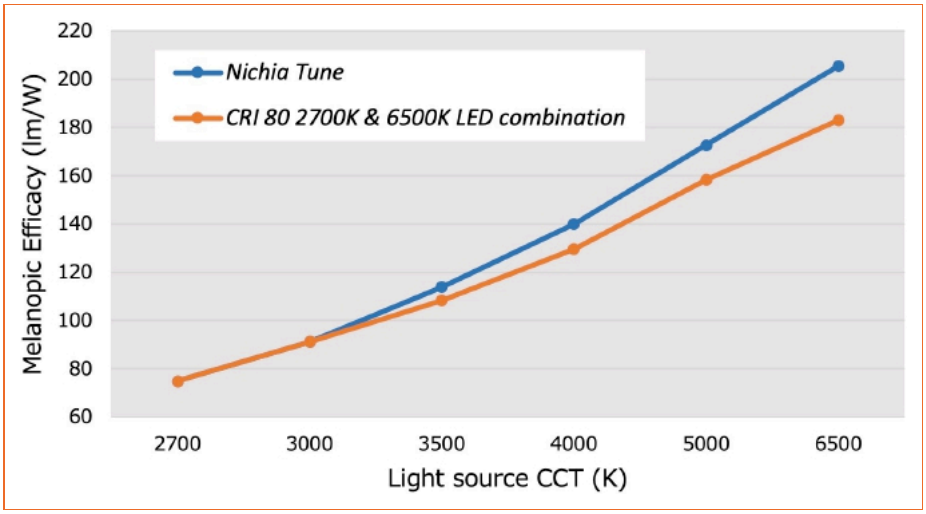

Figure 3: Melanopic performance of *Nichia Tune* and a currently available CCT tunable LED solution at different CCT settings of the light sources.

main advantage of mixing these sources is the high MR at cooler CCTs and low MR at warmer CCTs. Incandescent lighting, with a CCT around 2700 K is generally considered pleasant light for use in the evening and contains very little melanopic light, which is evident with an MR value of just over 0.5. The *Nichia Tune* with the same CCT has an even lower MR value of 0.421 (**Table 2**). **Figure 2** shows the comparison between the *Nichia Tune* and the equivalent standard illuminant with the same CCT for the full tunable CCT range. Besides having decreased melanopic light at the warmer CCTs, it has an MR that is higher than daylight at the cooler CCTs. It is a truly circadian enhanced tunable color temperature solution.

In the current market environment, energy efficiency is still considered one of the primary properties of a lighting product. When comparing the efficacy of the melanopic light, *Nichia Tune* outperforms existing CTT solutions. **Figure 3** shows the higher melanopic efficacy (**Equation (3)**) of the *Nichia Tune* at different CCT settings. At higher CCTs the percentual difference in melanopic efficacy is largest, indicating the superior melanopic performance of *Nichia Tune* exactly where it matters. The luminous efficacy is still at the high end of most regulations and can certainly be considered an energy saving solution, while still maintaining high efficacy (**Figure 4**).

Tunable CCT	$\gamma_{mel,v}^{D65}$	MR
2700 K	0.381	0.421
3000 K	0.465	0.513
3500 K	0.586	0.647
4000 K	0.729	0.805
5000 K	0.918	1.013
6500 K	1.116	1.232

Table 2: Comparison of the melanopic daylight (D65) efficacy ratio ($\gamma_{mel,v}^{D65}$) and Melanopic Ratio for the *Nichia Tune*

The comparisons of performance of the *Nichia Tune* in **Figure 3** and **Figure 4** are made against a combination of Nichia CRI 80 2700 K LEDs and CRI 80 6500 K LEDs.

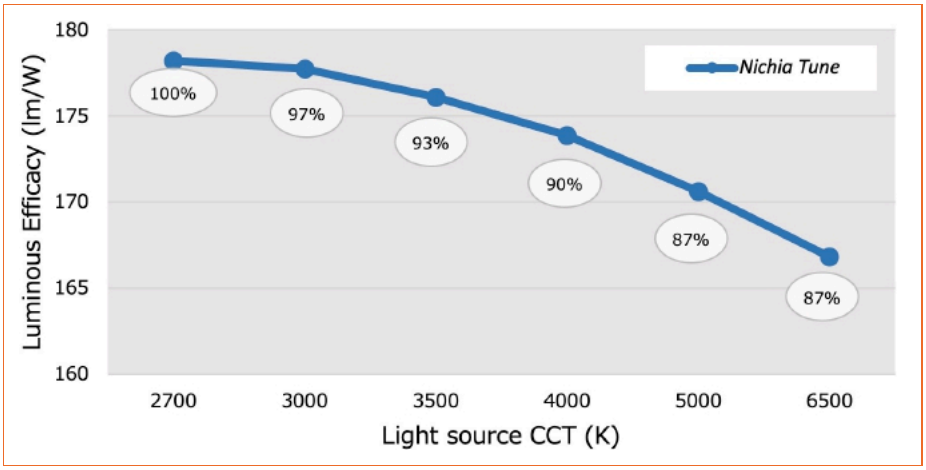

Figure 4: Luminous efficacy of the *Nichia Tune* at different CCT settings. The percentages indicate the relative luminous efficacy when compared to a tunable solution using CRI 80 2700 K & 6500 K LEDs.

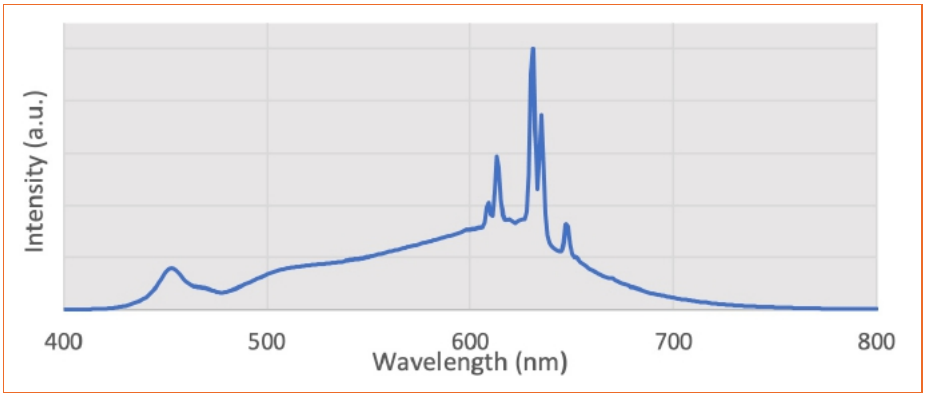

Figure 5: Spectrum of the first Nichia H6 Series 2700 K LED* (Part No. NFSW757H-V1H6).

Future Developments

For a melanopic optimized CTT product, having a high melanopic performance at the cooler color temperature range is ideal. On the other hand, for the warmer color temperatures, it is desirable for the light to have a high CRI. For the full CCT range, the light source is also expected to have a high luminous efficacy. As shown before, the *Nichia Cyan* enables the high efficacy and high melanopic performance for the melanopic part. The newly released Nichia H6 high CRI LED series will make it possible for CTT solutions to maintain a high efficacy even at the warm color temperatures.

The new H6 LED series takes advantage of a unique red narrow band phosphor technology, enabling a high CRI without sacrificing the luminous efficacy of the product. A 20% increase in luminous efficacy compared to most CRI 90 LEDs can be achieved with this phosphor technology, meaning these LEDs are capable of achieving a typical luminous efficacy of 200 lm/W, a minimum CRI of 90 and an R9 value of at least 50. In **Figure 5**, the distinct emission in the red part of the spectrum is seen in the 2700 K version of the H6 series.

Currently the H6 series is ideally suited as a stand-alone product for high CRI lighting solution. By combining two different CCT H6 series LEDs, a high CRI non-melanopic CTT solution is created. Further development and optimizations of the *Nichia Cyan* and the H6 series are still needed to enable a truly high CRI melanopic CTT lighting product. It is expected that in the near future these optimized versions of these series will be ready, which will be ideally matched for melanopic high CRI CTT lighting solutions.

Conclusion

Color temperature tunable (CTT) lighting products are becoming part of lighting manufacturers standard portfolios. Smart lighting solutions becoming more intelligent and independent of direct user-input are key factors in the popularization of CTT solutions. The *Nichia Tune*, consisting of the new *Nichia Cyan* LED combined with a standard CRI 80 2700 K LED, bring increased circadian performance to CTT solutions. In the morning the light can be energizing and vibrant, and in the evening the light can be tuned to feel warmer and more relaxing. And it doesn't end there. Developments are still ongoing to improve the performance of light sources that are part of CTT solutions. ■

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AUTHOR: Menno SCHAKEL
As a Technical Marketing Engineer for Nichia, Menno Schakel focuses on customer's technical requirements, bridging the gap between the customer and Nichia's product research and development. Menno has worked as an optical measurement specialist at Philips Lighting and a British measurement laboratory in his earlier career. He is also a member of several CIE Division 2 technical committees and currently holds the committee chair of TC2-89, developing a measurement method for Temporal Light Modulation.

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Best of DALI

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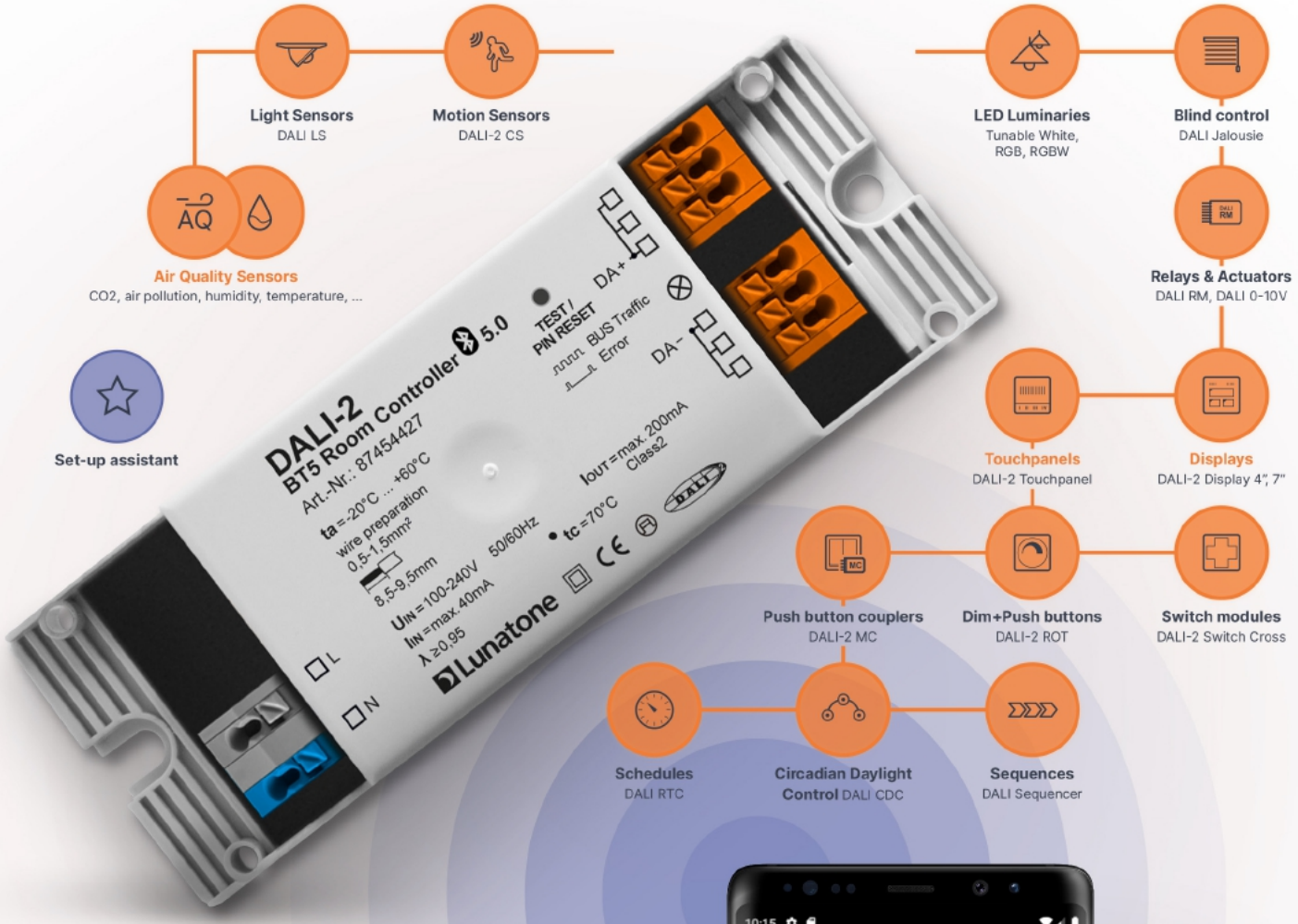

DALI-2 Room Controller

The DALI-2 Room Controller serves as an interface between **Bluetooth 5.0** and DALI. The device is especially suited for room solutions. The controller provides both the supply for the DALI line as well as the software for addressing, commissioning and control.

Via Bluetooth and the Lunatone smartphone application **DALI-Cockpit Mobile** the Set-up assistant can be accessed to comfortably set up the DALI installation. The application offers various configuration options and a customizable user interface to control connected DALI devices.

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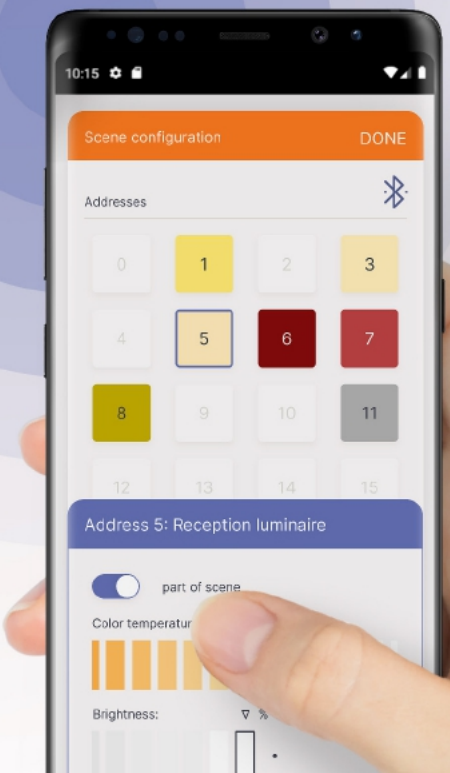


ANDROID APP ON Google play

DALI+ and Wireless to DALI Gateways Increase Connectivity Options for DALI Lighting Networks

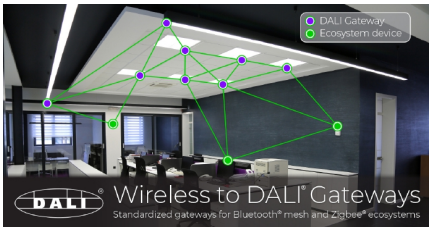
The launch of DALI+, a new brand for DALI over wireless and IP-based networks, along with new specifications for standardized Wireless to DALI Gateways, opens the door to greater choice and freedom for lighting specifiers, especially for IoT-based projects. Paul DROSIHN, general manager of the DALI Alliance, explains.

DALI is evolving to encompass both wired and wireless connectivity. Clearly, offering the industry greater choice is the right move because there are projects when one or the other solution (or a hybrid of both) is deemed the right fit depending on the specific requirements, environment and other factors.

In some instances, wireless lighting control may be identified as an ideal solution, especially in retrofit installations. One advantage of wireless is flexibility; it can be much easier to add sensors and new luminaires to an existing lighting network, or to relocate devices when a building is refurbished or repurposed. Not needing to lay new data cables through walls, ceilings or floors can be a considerable advantage in time and expense (although, of course, luminaires and other lighting devices still require power).

On other occasions, there will be a tendency to choose wired network connectivity, including in large-scale infrastructure installations. Wired systems offer predictable network behaviour, and avoid any potential connectivity issues that may arise in a built environment. Also, DALI wiring can be installed along with the power cables.

Working with prominent collaboration partners, the DALI Alliance is standardizing the way that DALI lighting controls can be combined with wireless networking, as well as with IP-based systems.



DALI+™

DALI Lighting Control with Wireless and IP-based Networking

In May 2021, the DALI Alliance (DiiA), the global industry organization for DALI lighting control, launched DALI+ [1], a new brand that denotes DALI over wireless and IP-based networks.

DALI+ builds on the proven capabilities, features and advantages of DALI lighting-control features in wired (DALI-2 & D4i) options, and offers access to the same rich set of data from control gear, luminaires and sensors. DALI+ is differentiated by the method by which the DALI commands are transported, being carried over a wireless and/or IP-based medium rather than the dedicated 2-wire bus for communication used by DALI-2 and D4i.

The DALI Alliance has published a new DiiA Specification, which supports DALI+ across different carriers and enables certification of interoperable DALI+ devices. The first certification program will be DALI+ with Thread, a low-power, IP-based, wireless-mesh networking protocol.

In combination with a wireless carrier, DALI+ enables true wireless DALI, without any need to translate between protocols. The wireless DALI+ devices form a network, and a wired DALI link is not required. However, the new specification also supports bridges, which allow access to DALI wired luminaires or subnets from the DALI+ wireless network.

"The new DALI+ adds further flexibility and choice for all DALI users while retaining a focus on certification and interoperability"

PAUL DROSIHN

The introduction of DALI+ ushers in a new era of seamless, industry-standardized lighting control. DALI+ extends choice, flexibility and creative freedom to lighting designers and specifiers by supporting the development of wired, wireless and IP-based systems, using DALI throughout. DALI can now be specified, and designs can mix and match DALI-2, D4i and DALI+, according to the option that best fits. DALI+ enables lighting solutions that can easily scale to building-wide networks, or even across multiple buildings, by using new addressing features. The implementation of IP-based networks in commercial buildings allows IT systems and building automation services, including lighting control, to operate on a common platform, with features such as end-to-end security, unlimited scalability, and easy connectivity to other applications.

Leveraging the existing features of the DALI protocol, DALI+ networks connect sensors, controllers and luminaires in a data-rich environment. This enables real-time monitoring of energy and power usage, and access to diagnostics information for predictive luminaire maintenance, among many other examples.

DALI+ is supported by a new DiiA Specification, available from the DALI Alliance website, entitled 'Part 104 Changes and Additions'. This provides updates to the published Part 104 of the international IEC 62386 standard. The first version of this specification supports IP-based protocols such as Thread, Ethernet and Wi-Fi.

Initially, the DALI Alliance is developing tests that will enable a new 'DALI+ with Thread' certification program. Further DALI+ certification programs utilizing other carriers will follow.

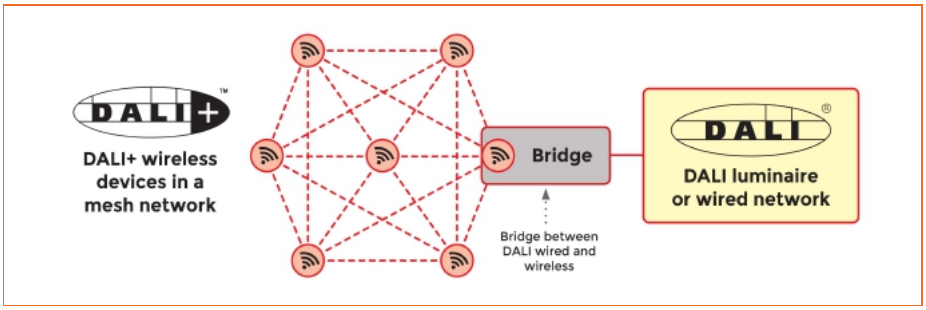


Figure 1: The new Part 104 Changes & Additions specification supports bridges, which allow a DALI+ wireless network to access DALI wired subnets or luminaires.

Wireless to DALI® Gateways

Standardized Gateways for Bluetooth® mesh and Zigbee® Ecosystems

The launch of DALI+ follows the release of two Wireless to DALI Gateway specifications [2] by the DALI Alliance. Gateways enable DALI lighting products to be incorporated into two widely-used, non-DALI wireless ecosystems, namely Bluetooth mesh and Zigbee.

Gateways effectively translate between protocols, with wired DALI devices on one side of the gateway and wireless ecosystem devices on the other side. In contrast, DALI+ solutions do not require translation, as the DALI protocol is used throughout.

Wireless to DALI Gateways provide the flexibility to incorporate DALI luminaires and other DALI devices into the control network, so it becomes very straightforward to

add lighting capabilities alongside the other features of the wireless ecosystem. The gateway specifications enable well-defined and consistent lighting behaviour, which is a fundamental feature of DALI lighting control.

Existing DALI devices can be used with these gateways, and there is already an extensive range of certified and interoperable DALI-2 and D4i products on the market. Additionally, the gateway specifications enable DALI control gear to report luminaire, energy and diagnostics data (as defined in Parts 251-253) to the wireless ecosystem via the gateway.

The two new gateway specifications published by the DALI Alliance are Part 341, covering Bluetooth Mesh to DALI Gateways, and Part 342, describing Zigbee to DALI Gateways. These specifications are also available from the DALI Alliance website. The Part numbers are aligned with the global, multi-part IEC 62386 standard for DALI technology. The specifications will be transferred to IEC for incorporation into IEC 62386.

D4i and DALI-2 Successfully Implemented in IoT Projects

While DALI+ and Wireless to DALI Gateways are now bringing wireless connectivity to DALI systems, DALI already contributes significantly to successful smart IoT-based lighting projects.

For example, multiple DALI subnets can be networked together to provide building-wide control. A single DALI application controller can control several DALI subnets, and application controllers can be connected together via an Ethernet backbone for example. Also, DALI systems can connect with other networks including building management systems (BMS) via non-standardized gateways.

Further capabilities are available from the use of D4i, which facilitates the addition of wireless nodes (also known as network lighting controllers) to luminaires. This enables standalone D4i luminaires to participate in remote lighting-control networks.

Harnessing sensor-rich lighting systems and standardized interfaces, building managers can benefit from new IoT capabilities including automated light-level and

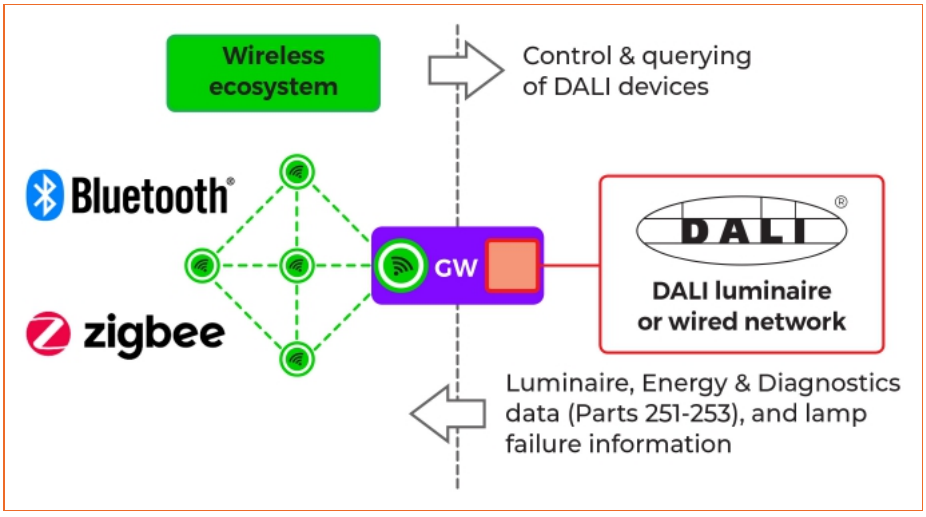


Figure 2: Gateways allow existing wireless ecosystems to control and query common DALI wired products. Devices in the wireless ecosystem communicate using their existing protocol, and can talk with the gateway (GW). DALI control gear can report luminaire, energy and diagnostics data to the wireless network.

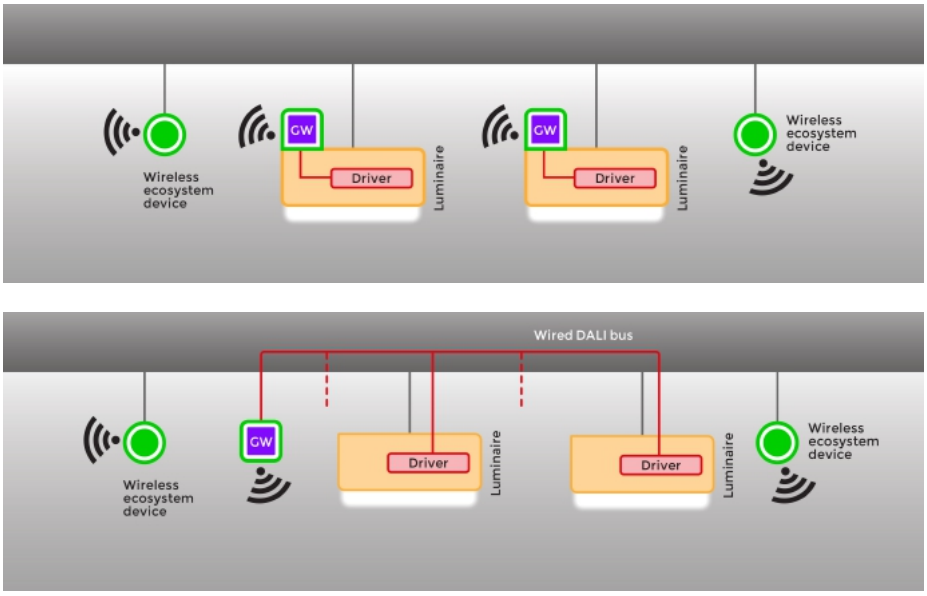
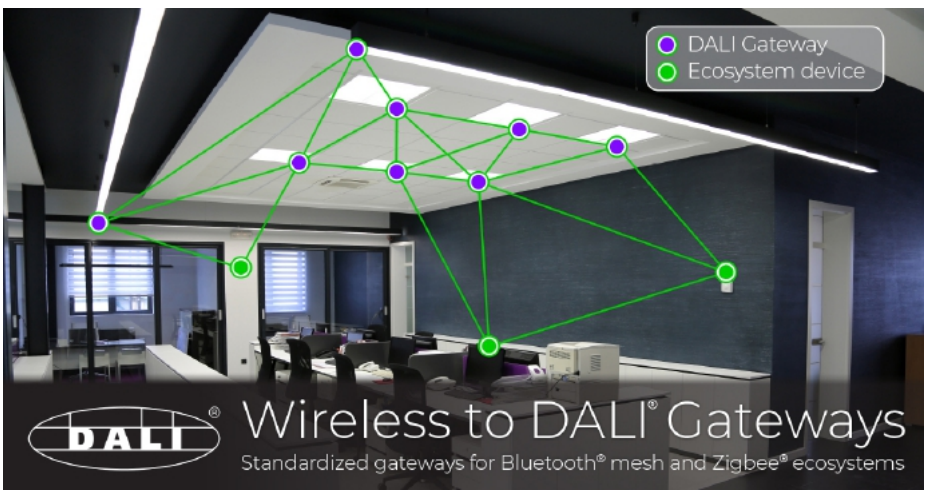


Figure 3: There are two main configurations for the DALI side of the gateway (GW).In the top diagram, the DALI-2 or D4i luminaires each have a gateway that participates in the wireless ecosystem, and also connects via an intra-luminaire DALI line to the LED driver. The bottom diagram shows a wired DALI subnet with several luminaires that are controlled by a single gateway (GW) to the wireless ecosystem.



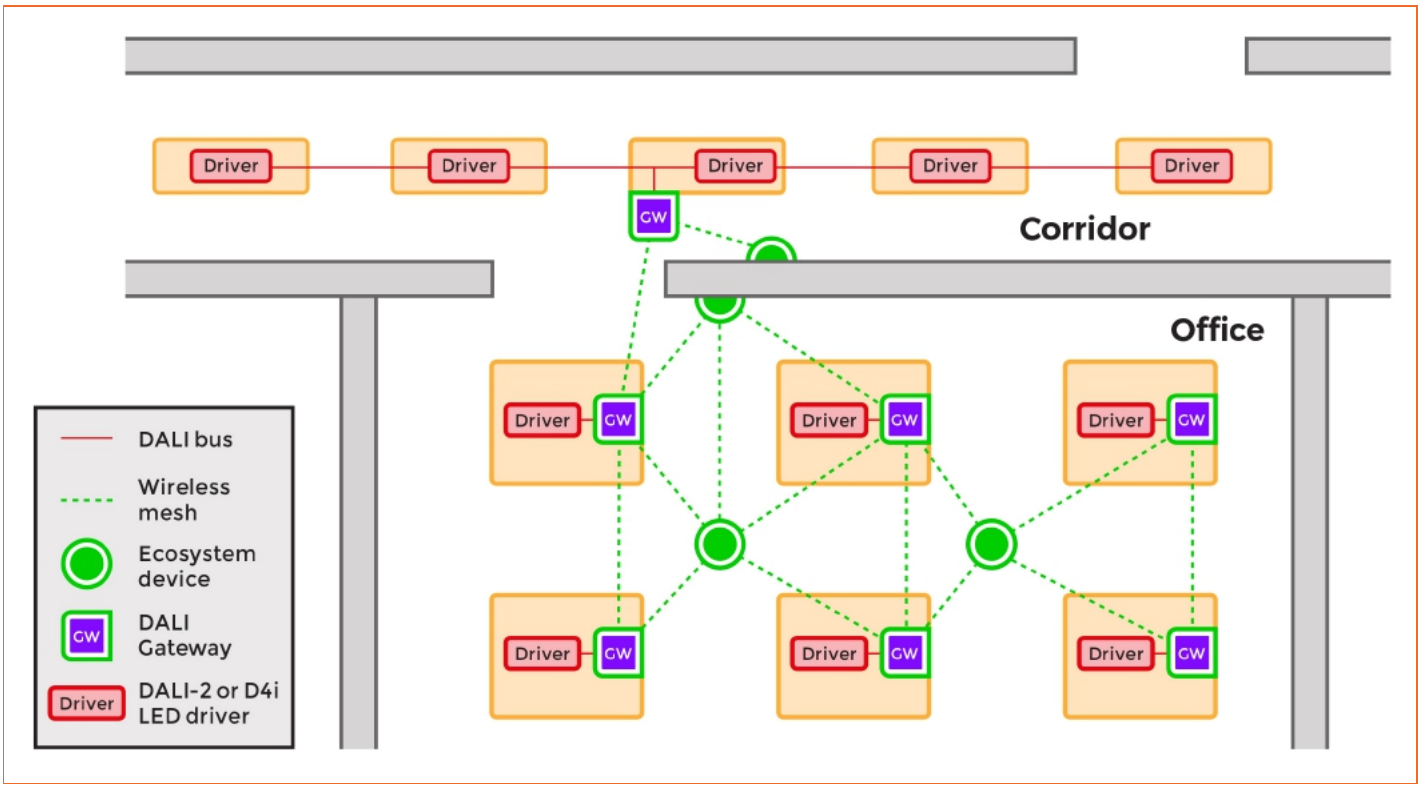


Figure 4: In this scenario, the office luminaires each have a gateway that forms part of the wireless network. In the corridor, a wired DALI line connects all the luminaires with a single gateway that also participates in the wireless ecosystem.

color control. Once again, DALI users can tap into advanced luminaire performance monitoring including energy usage and predictive maintenance, as well as enhanced services such as asset tracking and indoor navigation.

Summary

With its rich feature set, DALI is already positioned to participate in IoT environments. And now, the new Part 104 Changes & Additions specification and the two Wireless to DALI Gateway specifications add further flexibility and choice for all DALI users, while retaining a focus on certification and interoperability.

Following the publication of the new DALI Alliance specifications, tests are already in development that will enable certification of interoperable devices from different vendors. When the tests are ready, gateways will be added to the DALI-2 certification program. For DALI+, the initial focus is to establish 'DALI+ with Thread' certification. Further DALI+ certification programs utilizing carriers other than Thread are likely to follow, delivering further standardization, future-proof reliability, and interoperability. ■

For more information, visit https://www.dali-alliance.org

AUTHOR: Paul DROSIHN
Mr. DROSIHN was appointed as General Manager of the DALI Alliance in May 2019. Paul is a highly qualified and experienced management professional with more than 30 years' experience in the electronics and LED lighting industries. He has held a number of senior roles in management, sales, operations, business development and strategic marketing, at companies involved in electronics distribution, semiconductor manufacturing, precision optics manufacturing and management consulting. He is a Member of IEEE and AMBA, and a Fellow of the Institute of Leadership and Management.

About: DALI Alliance
The DALI Alliance (also known as the Digital Illumination Interface Alliance or DiiA) [3] is an open, global consortium of lighting companies that drives the growth of lighting-control solutions based on internationally-standardized Digital Addressable Lighting Interface (DALI) technology. The organization operates the DALI-2 and D4i certification programs to boost levels of cross-vendor interoperability. As lighting continues to evolve and converge with the IoT, the DALI Alliance is also driving the standardization of wireless and IP-based connectivity solutions.

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[3] https://www.dali-alliance.org

Why Wireless Control Networks Are Taking Over Commercial Lighting

Commercial connected lighting systems have long held the promise of providing building managers with advanced lighting controls that can deliver significant energy savings and an improved occupant experience, unlocking the full value of a building. As the appetite for lighting control in commercial settings increases, so too does the demand for data-driven smart building services that bring benefits far beyond illumination. The ubiquity of lighting provides the ideal foundation for an intelligent building.

In addition to providing valuable energy efficiencies and a more comfortable and productive experience for occupants, lighting control systems can serve as a central nervous system for a building and enable more efficient operation of other building systems, including HVAC and security. Lighting infrastructures can also establish a platform [1] that supports advanced building services, such as indoor navigation and asset tracking.

70-75% REDUCTION

in energy costs achieved through connected lighting and advanced lighting controls

ENTERPRISE IOT INSIGHTS, 2020

Do the Dollars Make Sense?

Lighting systems can account for 30 percent of all energy used in commercial buildings, providing facility managers and owners plenty of incentive to add advanced lighting control to reduce those energy costs. But control comes at a cost as well. In legacy control systems, the more advanced the control the higher the cost, and the expense associated with many legacy control systems has been prohibitive. The complexity of legacy systems has been another barrier to adoption. To feel more confident in their ROI, system owners and integrators need solutions that offer a low entry point to ownership and a high functionality-to-cost ratio.

Wireless networks have proven to be a more cost-effective option than their wired counterparts. On top of the added expense associated with wired lighting control networks, there is also a greater chance installation will disrupt day-to-day operations when deploying or upgrading the system, especially in highly active commercial or industrial environments. A wireless network provides significant cost savings with minimal disruption during deployment. Additionally, wireless platforms are easier to install and upgrade, offering the flexibility needed to respond quickly to changing business demands.

For small-scale systems, like those in a home or small office, legacy wireless networks are a suitable option, but there has been a common misperception that, when it comes to dependability in larger commercial and industrial environments, wireless networks cannot compete with a wired infrastructure. However, there is a solution that provides all the flexibility and cost benefits of a wireless lighting network while addressing any concerns regarding scalability or reliability.

The Future of Commercial Connected Lighting

Bluetooth® mesh networking [2] has emerged as the scalable and reliable solution for commercial lighting control that can turn the promise of data-driven smart building services into reality. Bluetooth mesh enables the creation of large-scale device networks. It is ideally suited for control, monitoring, and automation systems where hundreds or thousands of devices need to communicate with one another and where performance, reliability [3], and security are of the utmost importance. Advanced commercial lighting control systems is one use case that has rapidly embraced Bluetooth mesh. According to Rafal Han, CEO of Silvair, “Bluetooth mesh networking is the most robust and powerful low-power radio technology for connected lighting in commercial spaces.”

Thanks to its decentralized control architecture, efficient message addressing, and ability to reliably relay messages, Bluetooth mesh is quickly becoming the go-to choice for commercial connected lighting systems.

Decentralized Control Architecture

The reliability of a wireless lighting control network [4] is based on its ability to deliver a message from the switch to the luminaire. Many wireless networks are structured using the same architecture principles as wired systems. The signal from the switch is sent over the network to a centralized lighting controller that deciphers the message before sending it to individual luminaires. The need for messages to travel to and from a centralized controller introduces unnecessary inefficiencies in a wireless lighting control network.

Control systems based on Bluetooth® mesh do not require centralized controllers, as intelligence is distributed to all end devices. Using peer-to-peer communications and multipath message relay, Bluetooth mesh ensures reliable message delivery. For example, in a Bluetooth mesh lighting control system, switches and sensors do not communicate to a centralized controller which then controls the lights, but instead, they communicate directly with the lights. This decentralized control architecture enables systems to achieve significantly greater scale, reliability, and performance at lower costs while ensuring there are no single points of failure.

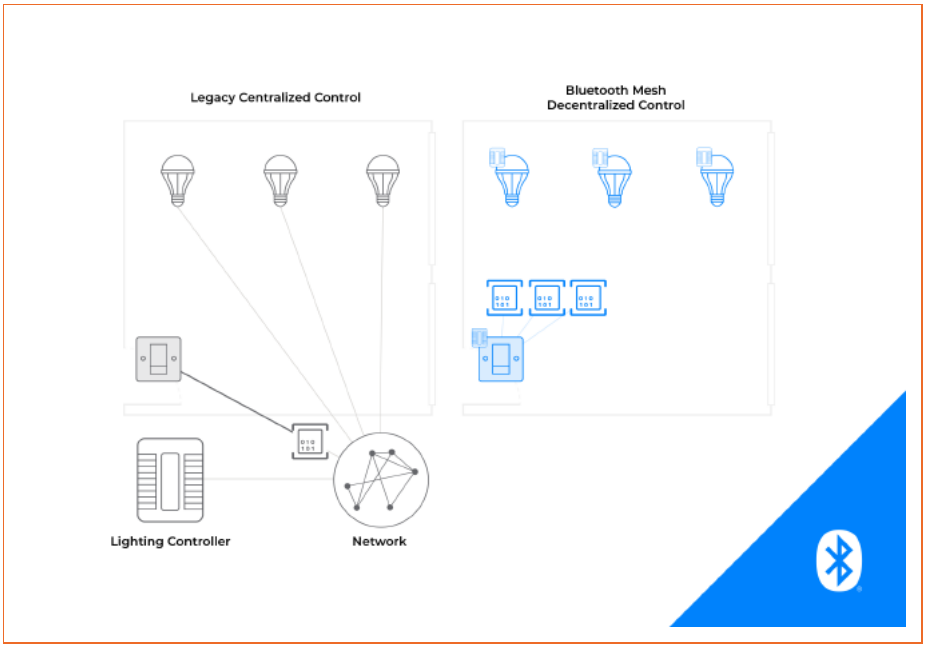

Figure 1: Control Architecture Comparison.

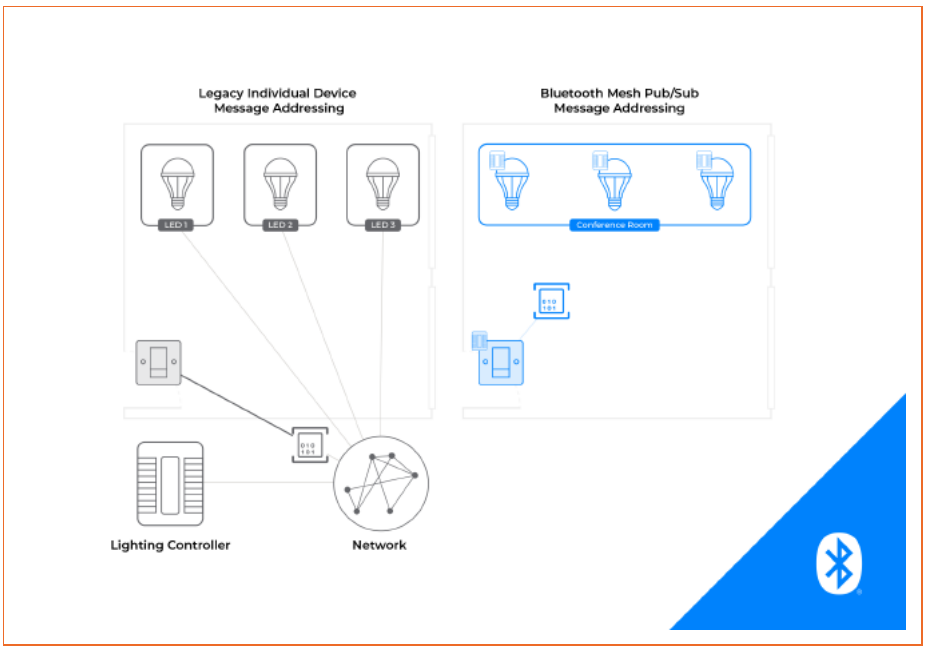

Figure 2: Message Addressing Comparison.

Efficient Message Addressing

Individual device addressing used by other wireless mesh communications systems is best suited for wired networks where most traffic is unicast. However, in wireless networks with significant multi-cast traffic, including lighting control systems, it can result in considerable scale and performance issues. In addition to individual device addressing, Bluetooth® mesh supports a unique publish/subscribe (pub/sub) addressing approach for multi-cast traffic. In pub/sub, devices such as light switches publish their messages to a group address like a conference room. All devices that should receive that message, such as the lights in the conference room, subscribe to that group. The pub/sub approach results in significantly lower messaging traffic on the network, leading to greater network scale and performance.

Efficient and Reliable Message Relay

When source and destination nodes are not in direct range of one another, messages must be relayed by other nodes in the network. Emulating legacy routing techniques used in wired networks for this task can lead to significant reliability, scale, and performance issues within wireless networks, especially those with multi-cast traffic. To address this challenge, Bluetooth® mesh adopted a managed flood message relay approach that is ideally suited for wireless networks, enabling them to scale to thousands of nodes while maintaining high performance and reliability [5].

The managed flood message relay architecture used by Bluetooth mesh, in addition to providing simple deployment and management, is inherently multipath and self-healing to ensure reliable message delivery. The managed flood message relay architecture, combined with its publish/-subscribe approach to group messaging, makes Bluetooth mesh uniquely suited to handle the significant amount of multi-cast messaging traffic that occurs in building automation solutions. Commercial and industrial lighting is an ideal use case for the deployment of a Bluetooth mesh network.

The Bluetooth SIG and the DALI Alliance

There is no better proof of the efficacy of Bluetooth mesh networking than its adoption by a global, long-established lighting control standards organization.

In May 2020, the DALI Alliance and the Bluetooth Special Interest Group (SIG) announced a collaboration that would bring together the organization responsible for the leading IoT standard for intelligent luminaires and the trade association that oversees Bluetooth® technology, the leading IoT standard for wireless lighting control networks. For the commercial connected lighting market to reach mass adoption, standards must be in place to ensure all lighting system components can interoperate smoothly. The two most important components of any commercial connected lighting system are the luminaires and the lighting control network.

On 15 April 2021, the DALI Alliance released a specification enabling the creation of a standardized gateway for D4i certified intelligent luminaires to be provisioned, managed, and controlled on a Bluetooth® mesh lighting control network.
The Bluetooth Mesh to DALI Gateway Specification establishes a bridge between the lighting controls and the sensor-rich luminaires that enables the movement and analysis of building operations data, removing one of the biggest barriers to realizing the true potential of IoT lighting. These sensor-rich lighting systems will allow data to flow freely to other building management systems, enabling more efficient operation of those systems and additional building services that can bring even more value to the building and its occupants.

Building off the Bluetooth legacy of universal interoperability in other product categories, the Bluetooth Mesh to DALI Gateway Specification provides global, cross-vendor interoperability between lighting components, wireless control systems, and intelligent luminaires.

"Combining Bluetooth mesh with DALI is a natural choice for the commercial lighting industry," said Paul Drosihn, DALI Alliance General Manager. "The combination enables sensor-rich lighting systems and will deliver powerful new IoT capabilities to building managers. This will include automated light-level and color control, advanced luminaire performance monitoring including energy usage and predictive maintenance, as well as enhanced services such as asset tracking and indoor navigation."

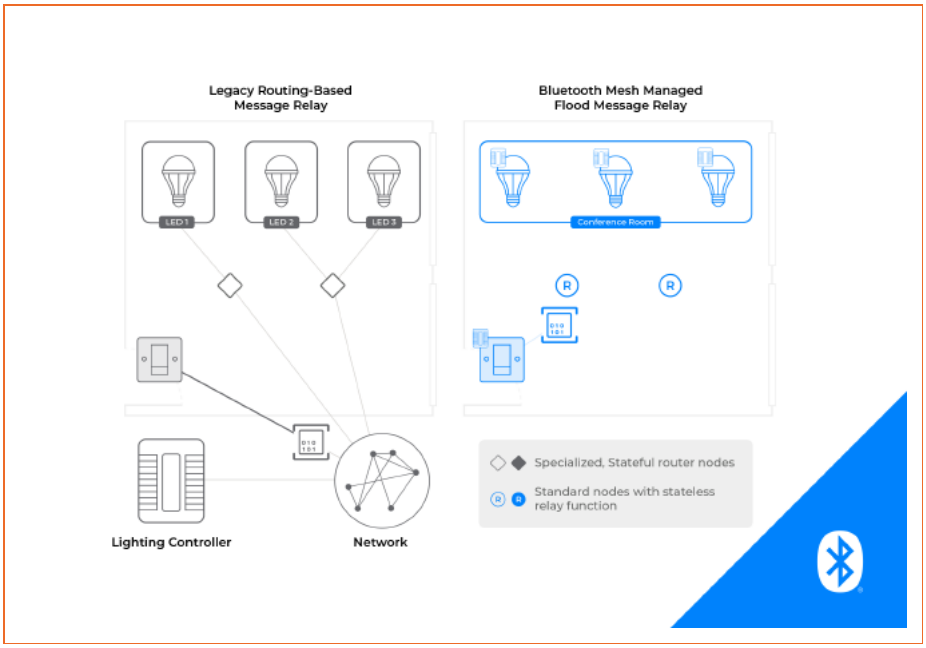

Figure 3: Message Relay Comparison.

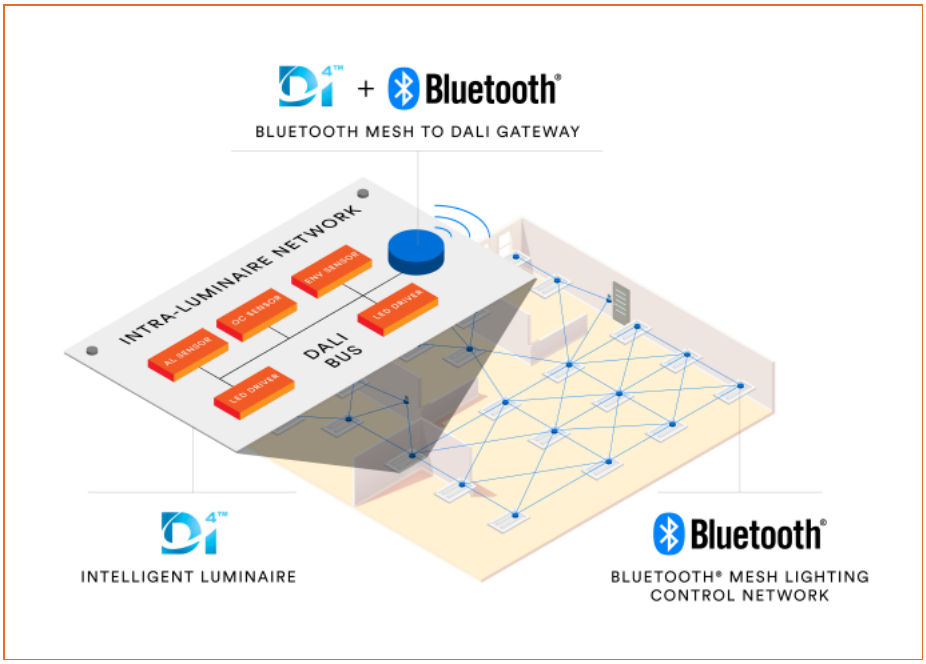

Figure 4: Bluetooth® Mesh to DALI Gateway.

Interoperability between lighting controls and intelligent luminaires benefits everyone on the value chain, from manufacturers to end users. The market will benefit from a wider selection of interoperable intelligent lighting components that will help accelerate the adoption of intelligent, IoT-enabled lighting systems in retrofit and new-build environments.

"I think two aspects are differentiating the way Bluetooth® technology interfaces with DALI," said Szymon Slupik, CTO and co-founder at Silvair. "The first is the true interoperability, which has been the cornerstone for both organizations. Interoperability is never given and done. It is more a mindset and a process. Bluetooth technology has been identified with universal interoperability in many product categories and we believe this can be done for lighting through a continuous process of providing precise specifications, running multiple interoperability test events, and the tight qualification procedures. And the second is the system architecture - the fully distributed, no-point-of-failure mesh, which brings new qualities to smart lighting. It has just become easy to implement and very reliable, offering the best user experience for both installers and end users."

According to a recently released article **[6]** by Slupik, Bluetooth® distributed control

architecture perfectly matches the DALI application controller concept. "It is not often that you see independent architectures that match and extend each other so well," said Slupik. "The technology match, together with the close collaboration between the Bluetooth SIG and the DALI Alliance, means that the market will benefit from a wider selection of interoperable intelligent lighting components. This, in turn, accelerates the adoption of intelligent, IoT-enabled lighting systems in retrofit and new-build environments. Ultimately, this leads to energy savings and enhanced comfort and user experience, which everyone can afford."

Standardization = Interoperability

The collaboration between the DALI Alliance and the Bluetooth SIG demonstrates the critical role that standardization plays in removing the barriers prohibiting wider adoption of commercial connected lighting. Standards have always been the catalysts for widespread market adoption. Without standardization, mass adoption remains out of reach. The collaboration will help ensure the development of devices from different manufacturers are capable of working together to establish a global, interoperable ecosystem of lighting products.

"We are excited to support this collaboration between the Bluetooth SIG and DALI Alliance," said Arnulf Rupp, head of standardization at OSRAM. "Establishing a standard Bluetooth® mesh interface for D4i intelligent luminaries will open up industry opportunity and enable the deployment of even more advanced, interoperable IoT-enabled commercial lighting systems while ensuring an equivalent light control behavior between both standards."

The Realization of Commercial Lighting Through Bluetooth Mesh

For years, the full potential of wireless commercial lighting control remained within the abstract. Over time, more and more installations began relying on Bluetooth® mesh networking to support their lighting control systems.

A growing ecosystem of Bluetooth® commercial lighting products from leading vendors such as Delta Electronics, Fulham, Leedarson Lighting, McWong, Murata, OSRAM, Sylvania, Zumbtobel, and others is helping drive a 130 percent CAGR of annual shipments of Bluetooth enabled commercial lighting solutions by 2026 [7]. Large-scale implementations in warehouses, retail, horticulture, and commercial offices, including a near 4,000 node deployment in a 22-story office building in North America [8], offer proof of Bluetooth mesh networking's scalability and reliability in demanding commercial settings.

$19.1 BILLION

in global commercial connected lighting revenue by 2029

GUIDEHOUSE INSIGHTS

The unique decentralized control architecture of Bluetooth mesh distributes intelligence across the network and eliminates single points of failure, bringing the resiliency, performance, and ease of implementation needed by installers, building managers, and end users in commercial installations. In addition, unlike other low-power wireless mesh networking technologies [9], Bluetooth mesh is a complete, full-stack solution that defines everything from the low-level physical radio layer through the high-level application layer, enabling easier product development and greater levels of product interoperability.

The Bluetooth Mesh to DALI Gateway Specification represents a key step in enabling lighting control systems to shift from a single-function solution to a platform that feeds building management systems and helps position intelligent lighting infrastructures as central to satisfying the growing demand for increased energy efficiency and improved occupant experience in sustainable, human-centric buildings.

"While lighting control in a wireless [Bluetooth®] mesh interconnecting DALI-based luminaires is the natural first application, we want to focus more on amplifying the value of luminaire data," said Slupik. "DALI (and D4i in particular) offers a great wealth of standardized luminaire data, including real-time energy use monitoring and predictive maintenance. We believe there is a great value in harvesting the data in an interoperable way. D4i is a great match to Bluetooth mesh, and we believe the standardized interface between the wireless system network and the DALI-based intra-luminaire network will open true cross-vendor interoperability. You will be able to wirelessly interconnect over Bluetooth mesh any certified D4i luminaires."

To help streamline the delivery of products to market, the DALI Alliance and the Bluetooth SIG are also working together to make it easier for vendors to complete both the Bluetooth® product qualification and DALI-2 and D4i product certification processes necessary to ensure interoperability. More information regarding product qualification and certification is expected later this year. ■

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Jason is a marketing program manager with the Bluetooth SIG who specializes in translating technical information into easy-to-read content. He enjoys sharing stories that show how people are using Bluetooth® technology to shape our wireless way of life.

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High-power Diode Lasers and Rotating Phosphor Converters Revolutionize the White Light Generation Process

In the past, when small light sources with high luminance were required, the creation of high-power white light had long reached technological limits. However, a new approach using blue diode lasers and rotating phosphor converters has now made it possible to have luminous fluxes of over 100 000 lm at luminances of more than 1000 cd/mm^2.

Introduction

A blue laser irradiates a rotating disk to which a ring of yellow phosphorus has been applied, and now, glistening bright light floods the room. What is here being tested in the lab is a new approach to generating high-power white light. To realize high luminous fluxes of over 100 000 lm, an LDM_{blue} high-power diode laser with a wavelength of 450 nm "pumps" a so-called phosphor wheel. The blue laser light is for the most part absorbed by this phosphor converter and then re-emitted at longer wavelengths. The result is a white broadband light spectrum. 150 000 lm can be achieved in continuous operation, which for short periods of operation can reach even 300 000 lm, and all this at luminance levels of up to 2000 cd/mm^2. This is roughly equivalent to focusing the light from 300 modern flashlights onto a tiny spot just a few millimeters in diameter.

Diode lasers in lighting technology? This will bring back memories for technology experts! Indeed, before diode lasers were further developed into industrial lasers since the mid-1990s, they were already used to create stage lighting effects. But at first, even experts did not have much faith in the technology. At their first trade show appearance, the founders of Laserline had to ask themselves what exactly they wanted to achieve in the industrial environment "with this better flashlight". It has since become known that this first assessment was a misjudgment. The diode laser has since gained a foothold in industrial material processing where it is used for welding, hardening or coating steels and non-ferrous metals. But it is also used in plastics processing, semiconductor manufacturing and for drying printing inks. So it seems all the more surprising that it is now apparently returning to its beginnings and being used anew in lighting technology. But this return is taking place under different circumstances. While no high-power diode lasers were available around two and a half decades ago, such lasers are now being established in industrial applications, as the first diode lasers in the blue visible light spectrum that achieve an output power in the multi-kilowatt range. This development allows the transfer back to new applications in the lighting technology as well.

Small Light Sources with High Luminance Pose a Challenge

To understand the path for developing this new approach, one must first understand the fundamental technical challenge, namely, providing very small, high-intensity white light point sources. Such light sources are needed today for a wide range of applications. These include conventional applications such as cinema and video projectors, floodlighting systems and maritime beacon technology. Important industrial applications include photolithography and solar simulation, that is, testing solar cells and photovoltaic systems by irradiating them with light similar to sunlight. All these applications require high-power white light sources that are characterized by a continuous light output and whose light can be effectively focused or collimated. And the latter, in particular, is anything but trivial because it requires an approximately point-shaped light center from which very high luminous fluxes are to emanate.

High-pressure Gas Discharge Lamps are the First Established Solution

Over time, one of the most successful approaches has been the use of ultrahigh-pressure gas discharge lamps. These lamps have been in use for around one hundred years. Today, they usually consist of a thick-walled quartz-glass tube equipped with a cathode-anode arrangement of solid tungsten electrodes and filled with a mixture of mercury and / or noble gas (argon or xenon). This gas mixture is ignited by applying a high-voltage pulse. An electric arc is created, the luminous center of which is located directly at the cathode. The extension of this light center is only a few millimeters which provides a very small light source with high intensity, effectively supporting the desired focus and collimation. This makes ultrahigh-pressure discharge lamps the high-power white light source of choice in many applications still to this day, of which Xenon ultrahigh-pressure lamps are the most common.

Depending on the application, however, lamps with mercury vapor fillings are also used, e.g. in photolithography.

But as successful as ultrahigh-pressure gas discharge lamps have been until now, their use is anything but unproblematic. Toxic mercury vapors and an internal pressure that rises from 100–400 bar during operation make them a risk factor and are leading to increasing legal restrictions on their use. Because of the risk of explosion, ultrahigh-pressure lamps must always be handled and operated with great care. The undirected spatial light emittance of the arc limits the usable light fraction for collimation and focusing dramatically, which significantly limits the light available at the target. There are also restrictions on installation, in addition to a rather mediocre color rendering quality and a relatively short service life that makes regular replacement necessary. Because of these disadvantages, there has been a constant search for other ways of producing concentrated high-power white light sources over the years.

White Light LEDs with Converter Technology are only Conditionally Successful

A real alternative seemed to have emerged when the first white-light LED with converter technology came on the market in 1995. The actual light sources were blue LEDs whose light was converted into a broadband white light with the aid of a cerium-doped YAG phosphor (also known colloquially as a phosphor converter). This approach had several advantages over the established gas discharge lamps: the technology was safe to use, i.e. there was no risk of explosion, nor were there any substances or concentrations of substances that were hazardous to health. The LEDs scored with high energy efficiency and a long service life. The broadband spectrum remained constant over the long term while the luminous flux was flexibly scalable. From individual LEDs to complete LED modules, a wide variety of configurations could be realized as needed.

Despite these advantages, the hope of being able to replace gas discharge tubes was only partially fulfilled. For as soon as small light sources with high luminance were needed, the new solution was found to have attained its limits: i.e. a high luminous flux could only ever be generated by using many LEDs placed next to each other, which limited the maximum achievable luminance and, for example, significantly reduced the contrasting effect of high-power lighting applications. An almost point-shaped light center, from which very high luminous fluxes should emanate, could not therefore be achieved with the new approach.

Blue High-power Diode Lasers Open up New Possibilities

This is where the new solution using high-power blue diode lasers comes into play. The use of this type of laser has made it possible for the very first time to effectively combine a very high luminous flux with high luminance and a light source with a long service life without any application hazards. The concept is initially based on the same physical principle that has already been used for LEDs with converter technology, i.e. transforming blue light into white light with the help of a phosphor converter. Beyond this basic principle, however, the two approaches differ significantly. Both the LED solution and until now tested laser concepts use single emitters with output power of about 3–5 W and then scale them up over the area via "numbering up." But the new approach resorts to compact laser bars with multiples of these output powers. This enables the use of new high-power blue diode lasers which provide up to 2000 W of output power at 450 nm wavelength in continuous-wave operation.

Such high laser powers are made possible by a new design concept for blue diode lasers, based on a patented laser architecture already used for infrared diode lasers. Instead of combining a large number of individual emitters, high-density laser bars are used. These, in turn, can be combined to form compact stacks of bars, the so-called stacks. A single laser bar combining a large number of single emitters on a semiconductor element can already provide over 75 W of power. Active bar cooling prevents the high-power density from damaging the heat-sensitive diodes. By connecting these bars to form entire stacks, higher laser powers can then be systematically built up [1].

The output radiation of the bars and stacks is combined by special optics and then either focused directly or coupled into an optical fiber. The resulting beam quality at output powers of 300 W or 800 W is up to 20 mm–mrad. For output powers of up to 1.5 kW, beam parameter products of 30 mm–mrad are available for the blue diode laser, and beam qualities of 60 mm–mrad for powers of up to 2 kW. For the fiber coupling, different optical fibers from 400 µm up to 1000 µm core diameter can be used, depending on the laser system and the application requirements. In addition, the entire laser system is designed as a compact 19" rack, such that the blue high-power diode laser supports the construction of very space-saving application configurations.

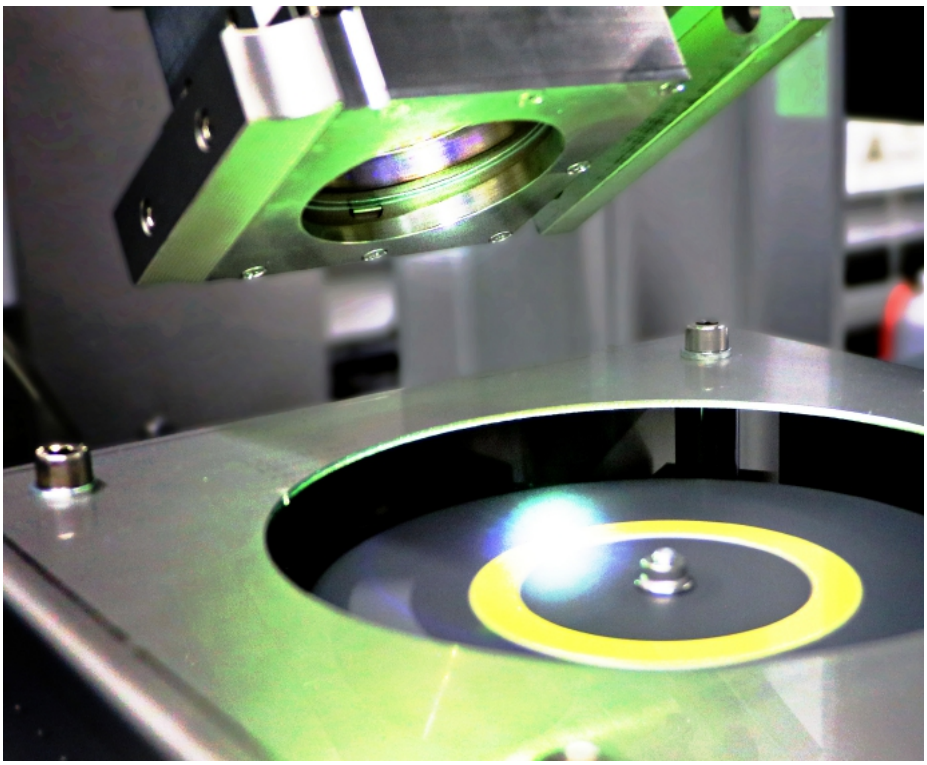

Figure 1: To realize high luminous fluxes of over 100 000 lm, an LDM_{blue} high-power diode laser with a wavelength of 450 nm "pumps" a so-called phosphor wheel. ©Laserline

A Laser that "Pumps" the Rotating Phosphor Converter

In order to make optimum use of the high output powers of the blue diode laser for generating high-power white light, the established concept of phosphor conversion also had to be modified. The energy input of the high-power blue diode laser is much higher compared to that of single emitters. The key challenge therefore is how to distribute the energy input of the blue high-power diode laser as effectively as possible over a larger area, thus maximizing the available power. In the past, mainly static converters had been used for this conversion process.

However, these converters are only suitable for lower power ranges and are thus not suitable for those in a higher range. In order to realize a thermally stable conversion process even at high energy input, a phosphor wheel is used whose disk rotates at over thousand rounds per minute during the process. The laser spot at a size of 15–20 mm^2 thus irradiates each position of the phosphor wheel only very briefly at a time. In this way, high laser power can be applied without overheating the converter while a correspondingly high light output can be generated. In addition to this optimized thermal management, the process also benefits significantly from the good focusing properties of the blue diode laser, which (with variable spot sizes and up to 20 mm–mrad beam quality) provides excellent conditions for a precise adaptation of the irradiation to the phosphor converter. Depending on the thermal management and size of the phosphor wheel, either the laser power can be increased or the spot size can be reduced. For the technology demonstration, a phosphor converter of the material type "yellow phosphor" with an outer diameter of 64 mm is used.

The process's optical conversion efficacy is 200–280 lm/W of laser power [2], which is averaged to a value of 230 lm/W for further luminous flux calculations. The system generates a continuous high-power white light emission with a wavelength spectrum of 450–750 nm. During the warming up of the phosphor wheel at 630 W laser power, an initial spectral shift (≈ 5 nm) of the center wavelength is occurring, which results in a stationary wavelength spectrum after approximately 120 s. The wavelength spectrum shows an increased intensity peak at the laser wavelength of 450 nm, as a result of the scattering of the incoming beam by the phosphor. In order to ensure eye safety for visual illumination or projection applications, the wavelength spectrum must be balanced regarding the blue intensity peak by wavelengths filters, which can be precisely applied due to the narrow bandwidth of the blue laser. The filtering of light however generally reduces the efficacy. This differs from industrial measurement applications, where the wavelength spectrum including the blue high intensity peak usually can be fully exploited. The available high luminous flux provides additionally a solution for wavelength sensitive applications, for which either one or multiple wavelengths can be extracted by e.g. selectively reflecting mirrors. Alternatively, the spectrum can be adjusted by filters to e.g. match the sensitivity of sensors. Since the emitted wavelength spectrum is dependent on the phosphor material type, the variation of the phosphor material allows for a choice of the wavelength spectrum.

The generated white light can be focused using optics with reflector diameters of 50–100 mm and can be scanned and thus also used for special exposures, for example. The size of the light source can be flexibly adjusted. The use of collimating optics ensures an adjustable residual divergence of less than 5°, while the emitted wavelength spectrum can be modified according to application requirements by selecting the phosphor converter accordingly.

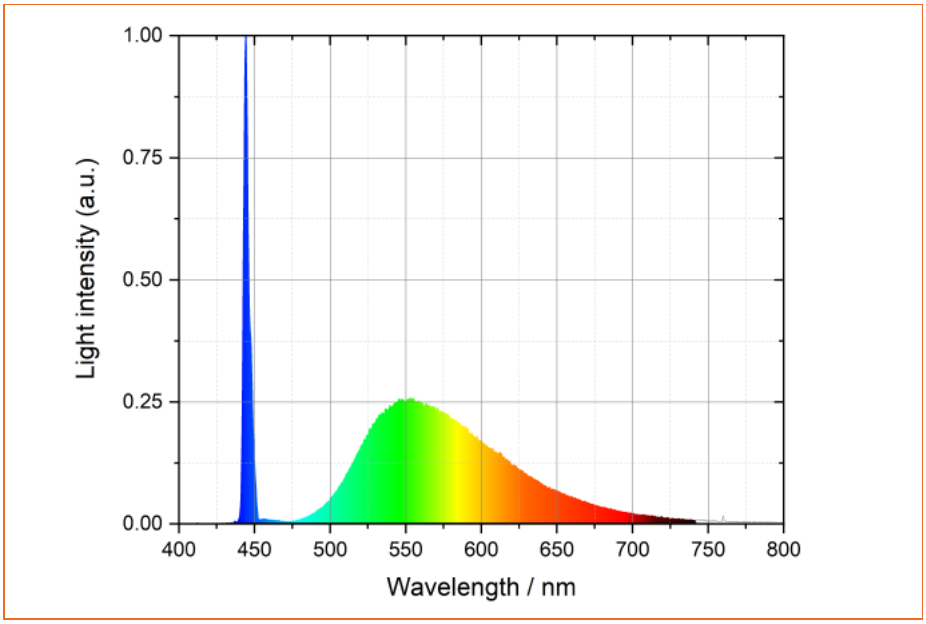

Figure 2: Emission spectrum of the white light generated by the Laserline blue laser system in combination with a phosphor wheel. ©Laserline

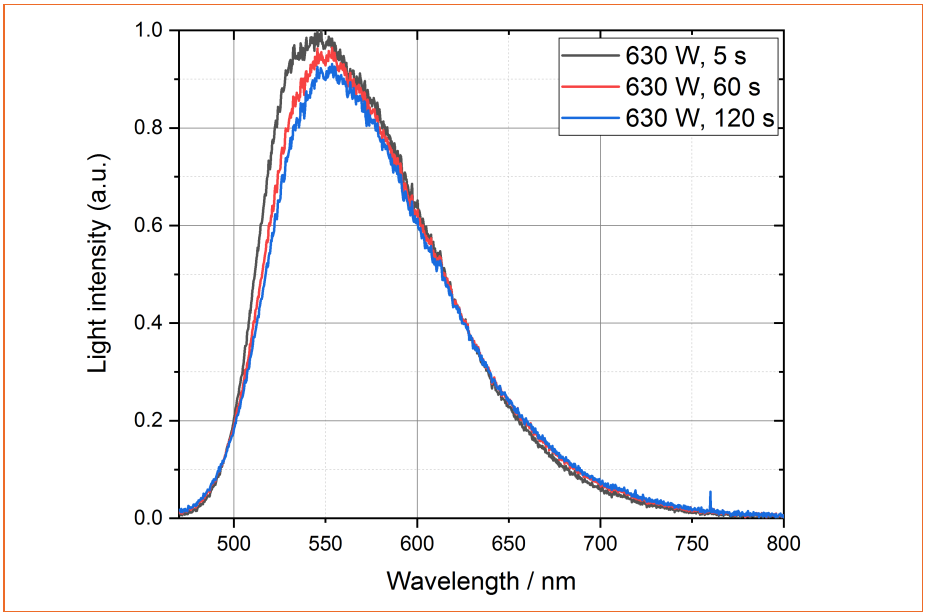

Figure 3: Initial center wavelength shift during warming up of the phosphor wheel at 630 W laser power with resulting stationary spectrum after ≈ 120 s. ©Laserline

Conclusion

The systematic combination of the established phosphor conversion process with high-power diode lasers has resulted in a process that opens up unprecedented possibilities for generating high-power white light with high light source luminance levels of more than 1000 cd/mm^2.

The above-mentioned luminous fluxes of 150 000 lm in continuous operation and 300 000 lm in short-term operation (determined by the 180° full-angle measurement) are worldwide the first demonstration of the capability of this new technology approach. In the test runs conducted to date, only a maximum laser output power of around 630 W was used in continuous operation. This means that not even half of the current power spectrum of blue diode lasers has been utilized. With further development of this technology approach, e.g. improved thermal packaging, optimized phosphor wheels or simple pulsed laser application, more than 200 000 lm in continuous operation are well within reach.

Due to efficient light collection capabilities on the phosphor wheel very high luminance levels are possible in the target area. With 1 kW laser power, for example, a luminous flux of 230 000 lm and a maximum luminance of 490 cd/mm^2 could be achieved in the target area. Exploiting the current maximum power of blue diode lasers (2 kW) would therefore allow for a luminous flux of 460 000 lm and luminance in the target area of almost 1000 cd/mm^2.

As of today, this solution enables new capabilities for applications in industrial measurement, e.g. solar simulation or material characterization, and in wavelength sensitive applications, which can be enabled by the extraction of single wavelength from the high luminance white light. For less demanding applications as in light projection or beacon technology, this approach has the potential to enable a new field for high power solutions, which can not be covered by other conventional white light generation methods. The new approach has made available for the first time a high-power white light source that impresses with high luminance in the light source and target area, along with its low-hazard application and long service life.

The blue diode lasers thus make a significant contribution to the development of white light technology in terms of significantly higher luminance levels, a continuous emission spectrum all through their service life, and compliance with environmental standards. ■

Laserline GmbH
Laserline was founded by Dr. Christoph Ullmann and Dipl.-Ing. (graduate engineer) Volker Krause in 1997. Laserline's powerful lasers meanwhile have been firmly established in many production chains.
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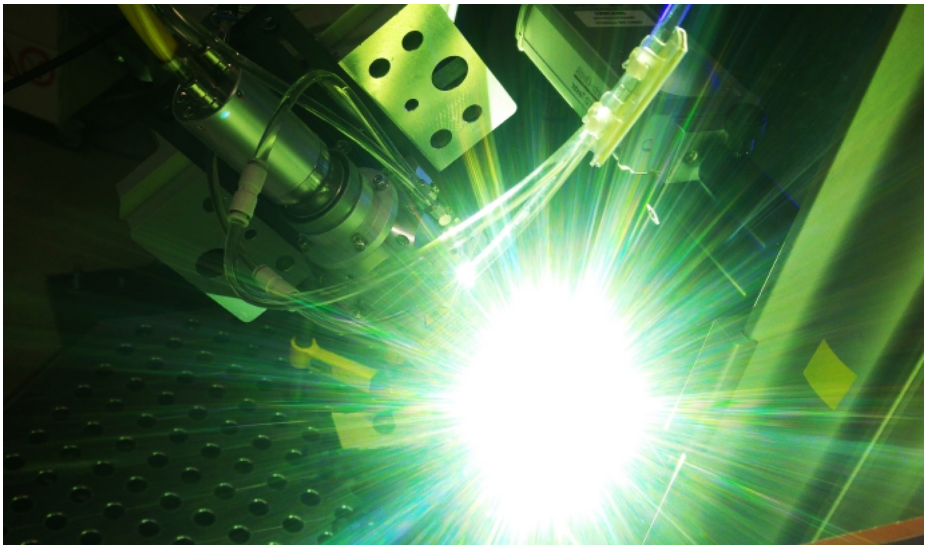

Figure 4: The blue laser light is for the most part absorbed by this phosphor converter and then re-emitted at longer wavelengths. The result is a white broadband light spectrum. ©Laserline

Figure 5: The entire laser system is designed as a compact 19" rack, such that the blue high-power diode laser supports the construction of very space-saving application configurations. ©Laserline

Package Level Thermal Analysis of White Light-emitting Diodes Based on Local Phosphor Particle Opto-thermal Behavior

Thermal management is among important topics that extend efficiency, efficacy, and reliability of phosphor converted light emitting diodes (Pc-LEDs). Depending on the spectrum-based phosphorescence properties of phosphor particles and their interaction with millions of incoming blue light rays, relatively high values of heat generation can be expected in these micron-sized particles. Consequent results are reduced conversion efficiency (thermal quenching) and even matrix carbonization in high power LEDs. Based on our previous research, local heat generation characterizations of phosphor particles are embedded in a detailed thermal analysis of a typical Pc-LED with a conformal phosphor coating, while different phosphor concentrations and radiative powers of the chip are considered. Although a significant amount of research work has been devoted to macroscopic thermal modeling of this phenomenon by considering uniform material properties distribution for matrix and phosphor particles, detailed particle-based analysis which include spreading thermal resistance inside the silicon matrix is still missing. The results of this research will help reach a balanced optical and thermal design for conformal phosphor coating Pc-LEDs for high lumen extraction, better color quality and a longer lifetime.

Introduction

Effective thermal control techniques in order to extend efficiency, efficacy, and reliability of phosphor converted light emitting diodes (Pc-LEDs) relies on a fundamental understanding of phenomena leading to heat generation in these devices [1]. The color conversion process has been shown to be one of the major heat generation areas in PC-LEDs where temperature increases above 300 °C have been reported [2,3]. A temperature increase in phosphor particles can lead to thermal quenching or even matrix carbonization [3,4,5]. However, the reason behind this intense temperature increase of micron scale sized phosphor particles is still a dilemma in the lighting community.

Our recent opto-thermal analysis [6] has revealed that exposing phosphor particles to 0.1 W/mm^2 blue light irradiance can lead to heat generation in excess of 100 W/mm^3. Typical blue LEDs with Lambertian emission patterns have these irradiance levels in a radius of 0.5 mm above the chip. This will target the particles in conformal phosphor coated Pc-LEDs in which phosphor particles are usually dispersed inside a low thermal conductivity silicon matrix. Generated heat in these particles mainly stream toward the chip and package and a small portion is dissipated toward the surrounding medium. However, micron scale sized heating areas in comparison to milli scale sized matrix and chip, and low thermal conductivity of the particles and matrix lead to relatively high spreading of thermal resistances [7,8]. Thus, accurate thermal characterization of Pc-LEDs, and specifically phosphor particles, can't be achieved unless a particle based approach (which ensures the inclusion of spreading thermal resistance effect) is used [9].

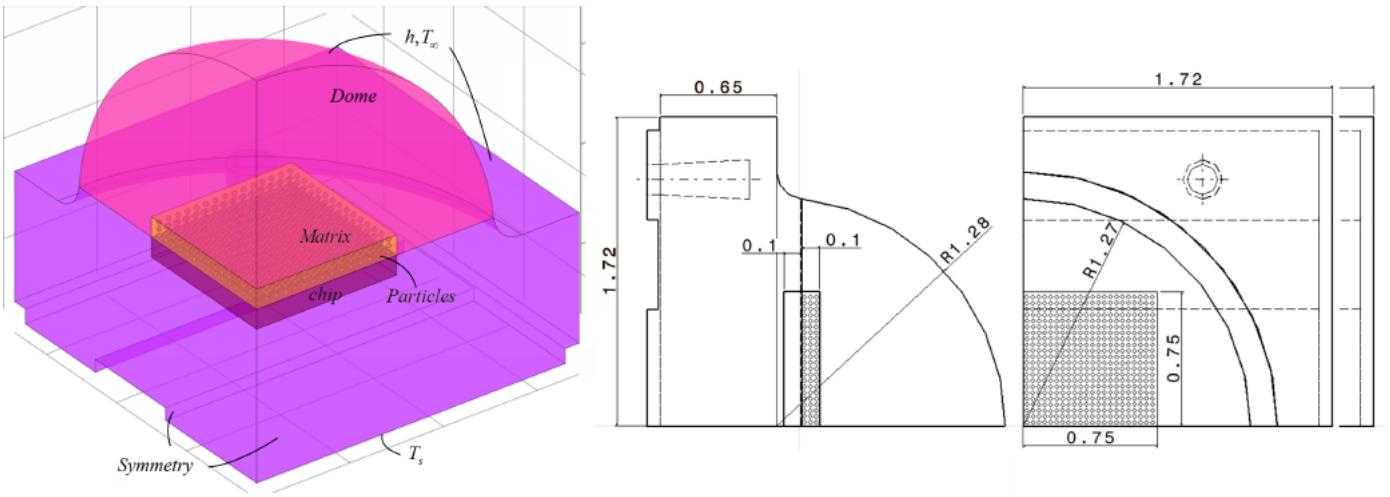

Figure 1: Component listing, boundary conditions, and symmetry surface view of the quarter of the LED (left), geometrical illustration of main sizes in the CAD design (right).

Based on location-based heat generation of phosphor particles, a detailed three-dimensional finite element method (FEM) for the thermal simulations of a Pc-LED package with conformal phosphor coating over chip are performed in commercially available COMSOL Multiphysics software. Particle diameters are set to be 25 µm like average particle size in [6]. Thermal characterizations are performed for different phosphor dispersion densities, coating thicknesses, and chip power levels. Although significant research work has been devoted to macroscopic thermal modeling of this phenomenon by considering uniform material properties distribution for the matrix and phosphor particles, detailed particle-based analysis, which include spreading thermal resistance inside the silicon matrix, will help reach a balanced optical and thermal design for conformal phosphor coating Pc-LEDs.

Computational Approach

Due to the symmetry in an LED package, only a quarter of the LED package is modeled as shown in **Figure 1**.An LED chip with a thermal conductivity of 48.12 W/mK, thickness of 100 µm, and square cross section of 1.5 mm is embedded inside the package with a thermal conductivity of 170 W/mK. Emitted blue light with a peak wavelength of 475 nm and radiation power of 1 and 2 W, is emitted from the surface of the chip in Lambertian shape and is absorbed by phosphor particles inside the silicon matrix coated with thicknesses of 100 µm and 200 µm over the chip. Photoluminescent phosphor particles absorb the blue light and emit yellow light with a peak wavelength of 550 nm, and during this process due to quantum losses and stokes shift, part of the energy converts to heat. Location based heat generation values of phosphor particles are derived from our previous study and a detailed analysis of the process is provided [6].

By neglecting the scattering effect between particles, heat generation density of particles ($\dot{Q}_{gen}$) can be normalized based on the radiative power of the LED (E_{rad}). Imported normalized location-based heat generation of phosphor in thermal simulations can be seen in **Figure 2**. There is a major peak at the center of the matrix in contact with the chip, where the highest irradiance is expected. Abrupt reduction in heat generation can be seen in other regions. This behavior can be changed based on the emission shape of the chip. Moreover, re-scattering is expected in high density matrices which will amplify the values of heat generation, which is neglected herein. Furthermore, thermal quenching will result in a reduced quantum efficiency in phosphor particles. Particles with higher temperatures have shown to have lower quantum efficiency, which increases the self-heating amount. This issue will result in a higher temperature rise of the particles and medium. However, to simplify the evaluations, this effect is not considered in the present simulations. The overall average normalized heat generation density of phosphor in this study is assumed to be 10.9 mm^{-3}.

Generated heat in phosphor particles with a thermal conductivity of 13 W/mK conducts inside the silicon matrix with low thermal conductivity of 0.16 W/mK and mainly dissipates at the bottom of the

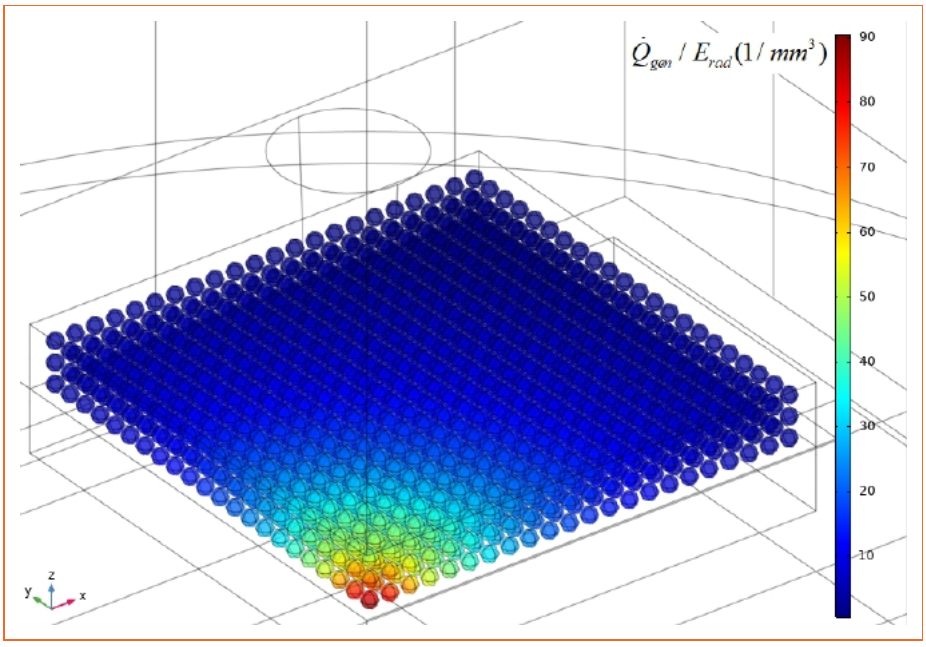

Figure 2: Normalized heat generation density of phosphor exposed to light rays.

package with a constant temperature of $T_s = 20\,°C$, and partially conducts to the dome with a thermal conductivity of 0.15 W/mK where convection to the ambient air at $T_\infty = 20\,°C$ and the convection coefficient of $h = 5\,W/m^2K$ occurs. By considering a 50% efficiency for the chip, uniform heat generation is also considered inside the chip. Steady state 3D energy equation is solved in the COMSOL Multiphysics [10]. Volumetric densities of 9.8% and 21.1% are considered for particles inside the silicon matrix. This will lead to having 2700, and 5808 particles inside a 100 µm matrix, and two times of the aforementioned values in 200 µm the matrix. This issue increases the computational cost of simulations that are performed at an optimum number of elements after performing an extensive mesh sensitivity analysis. Three-dimensional (3D) surface temperature analyses have shown that in both matrix thicknesses, there are concentrated temperature locations in centered phosphor particles while more uniform temperature distribution can be seen in other areas of the device. Due to this significant localized temperature size, data presentation is targeted on particles with the highest temperature. Temperatures are provided over a horizontal surface and a vertical line passing from the middle of the hottest phosphor as shown in **Figure 2**. Next, the average temperate of phosphor particles are obtained in different volume densities and matrix thicknesses.

Results and Discussions

Figure 4 provides the temperature distribution across the horizontal surface passing from the hottest phosphor particle (**Figure 3**) in 100 µm and 200 µm the silicon matrix in different radiation powers. It can be seen that by increasing radiation power, self-heating in centered particles results in having a higher maximum temperature in the matrix. On the other hand, due to low self-heating and lower impact of surrounding particles, no abrupt temperature rise in particles at the edge of the chip can be seen. Low temperature profiles can also be seen in the dome section included in the data acquisition surface. Localized temperature rises inside the coating highlights the necessity of accurate particle based thermal modeling of phosphor converted lighting devices. A linear behavior between radiation power and the temperature rise of phosphor particles can be seen in the same volume densities, indicating that thermal resistance of the coating is the same in different power densities (unless significant thermal conductivity change with temperature exists) and is dependent on the configuration of phosphor particles inside the matrix and thermal conductivities of phosphor and matrix material. The majority of the thermal resistance is due to heat spreading from small sized particles to much a larger heat sink and also the thermal resistance effect of neighboring particles that are arrayed beside each other. This issue can be an important factor in optimization of phosphor dispersion in silicon coating.

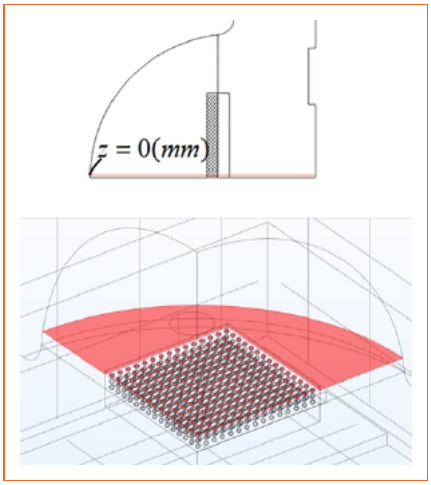

Figure 3: Data aquisition line passing from middle of the hottest phosphor (top), and data acquistion surface passing from the hottest phosphor (bottom).

It can be seen that in higher phosphor concentrations, higher maximum temperatures are achieved compared to lower density matrices. However, since phosphor has a higher thermal conductivity relative to the silicone, this issue alleviates the temperature increase of the matrix. Having more particles increases the overall thermal conductivity of the domain. However, at the same time, even decreasing the space of the heat generation region increases

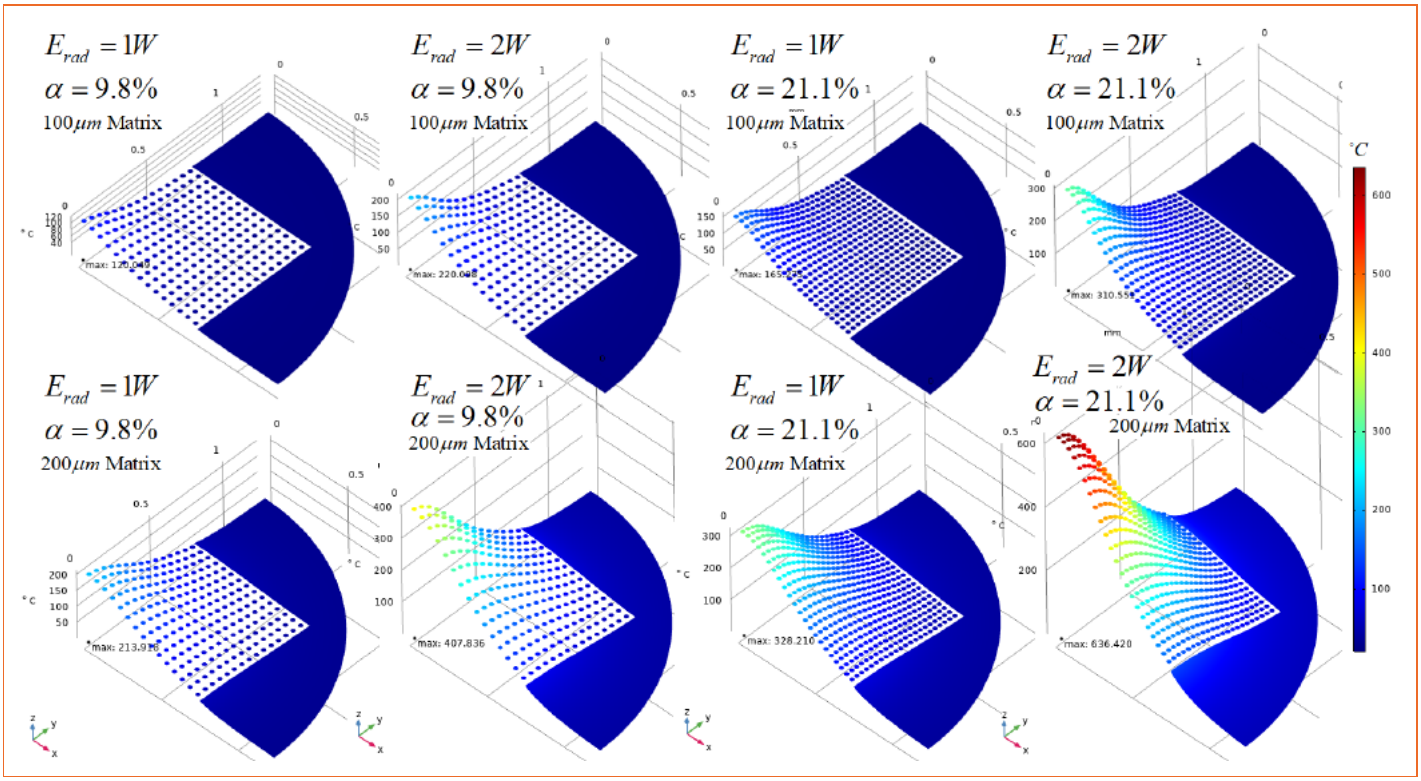

Figure 4: Temperature distribution across horizontal surface passing from the hottest phosphor particle (as shown in Figure 3) in 100 μm and 200 μm silicone matrix in different radiation powers and phosphor volume densities.

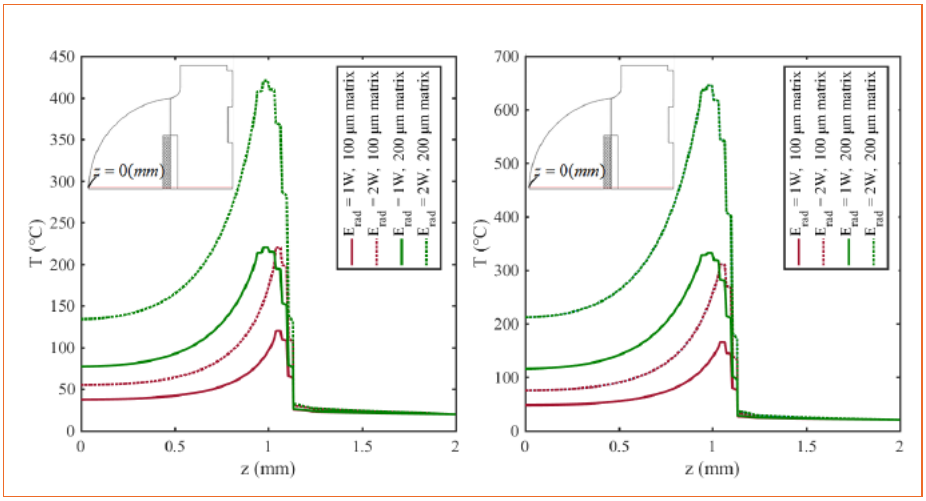

Figure 5: Temperature distribution in the vertical data line passing from the hottest phosphor, from top of the dome toward the package in volume density of $\alpha = 9.8\%$ (left), and $\alpha = 21.1\%$ (right).

the spreading thermal resistance effect. This highlights the importance of thermal conductivity of the host matrix. Significant thermal enhancement can be achieved by utilizing high thermal conductivity matrices.

A dome with a relatively lower thermal conductivity surrounding the chip also has a lower temperature, and maximum temperature is concentrated in the micron scale centered area which brings serious challenges in the experimental characterization of this phenomenon.

One of the outcomes of increasing the thickness of the silicone matrix is having higher maximum temperatures in similar volumetric densities of phosphor. Increasing the thickness of the silicon matrix will increase the one dimensional (1D) thermal resistance (or perpendicular thermal resistance) of the particles, while negligible changes occur in spreading thermal resistance. Due to this fact, one can see that temperature differences between the thin and thick matrixes is bolder in higher volume density matrices.

The effect of increased 1D thermal resistance in 200 µm matrix can be seen more clearly in **Figure 5**. This figure compares the temperature distribution of the LED in a vertical data line passing from the hottest phosphor, from the top of the dome toward the package. Elevated temperature rise, and higher maximum temperature are results of increased thickness of the matrix with the same phosphor volume density. This temperature rise can also be expected in the chip domain in real working conditions. However since the ideal heat sink (this case) is considered herein, no significant change in the chip can be seen. It can be seen that the highest temperatures are obtained in particles at the top of the matrix. However our previous study showed that in distances above 200 µm from the chip there is a reduction in temperature of phosphor particles due to a severe reduction in the value of heat generation. Temperature profiles in **Figure 5** reflects the challenges of experimental temperature measurement of particles. Utilizing surface temperature measurements over the dome, or junction temperature measurements will not capture the excessive localized temperature of phosphor particles. It is also noticed that using a thicker matrix in a similar volume density of particles elevates the average temperature of the particles which can lead to color conversion efficiency loss, and different CCT values in similar lighting conditions.

Enhanced Phosphor Dispersion

Based on the obtained results, possibilities on better thermal management of phosphor particles can be realized without relinquishing the optical performance of the coating. Since thermal conductivity of phosphor is approximately 100 times higher than the matrix, having higher volume density of particles in the center of the chip can not only increase the local thermal conductivity, but can also increase the optical performance of the matrix by increasing the re-scattering effect. On the other hand, thinner coating offers lower 1D thermal resistance. By combining these effects at the center of the chip, a new configuration can be introduced for the Pc-LED coating. To examine the proposed technique, we

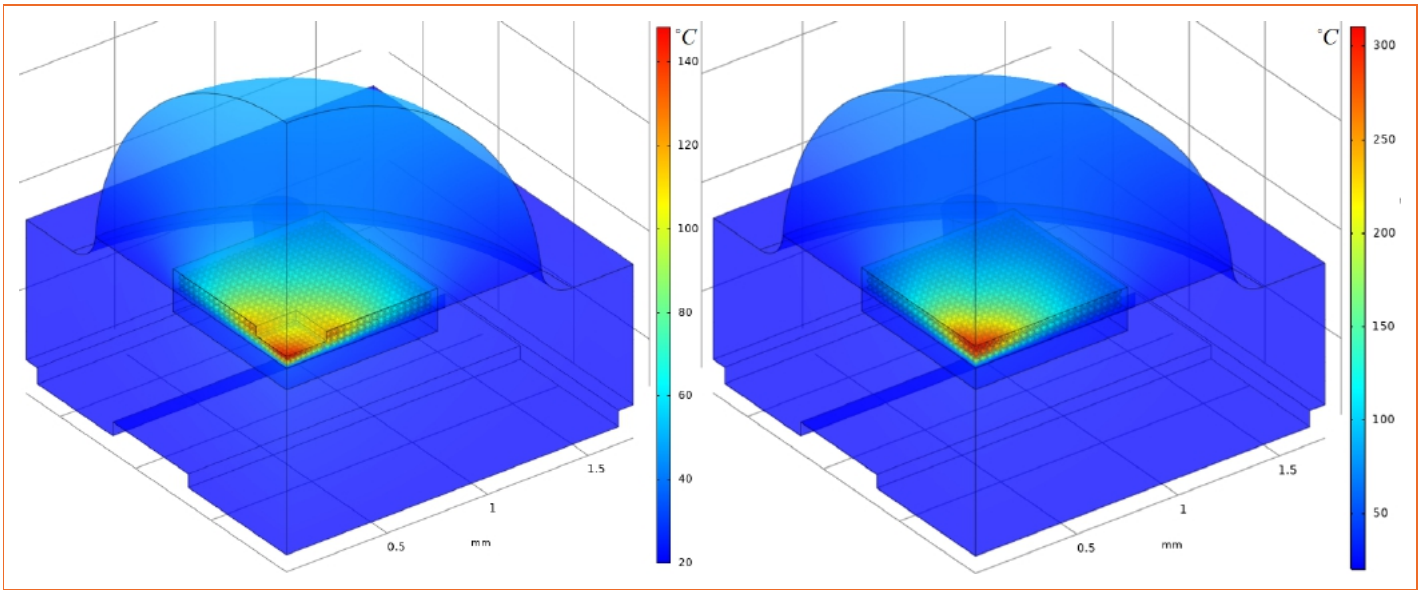

Figure 6: 3D temperature distirbution of Pc-LED with modified coating (left), and coformal coating (right) at a radiant power of 2 W.

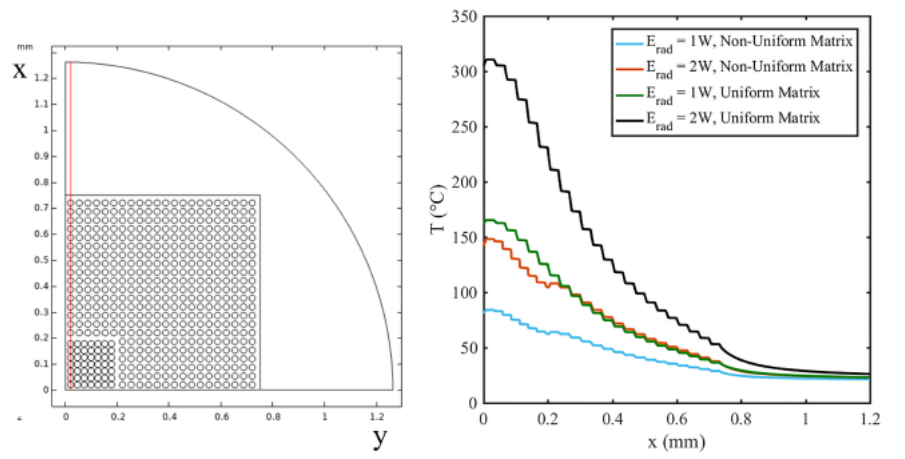

Figure 7: Temperature profile passing from the hottest particle in horizental direction.

have compressed the coating of Pc-LED with volume density of 21.1% and thickness of 100 µm at 400 µm × 400 µm region at the center of the chip by 33% and performed comparison simulations. Presented in **Figure 6**, by having the same number of particles, but more localized particles at the center and nearer to the chip, obtained maximum temperature is reduced in excess of 50%. For better comparison in a different horizontal direction, temperature profile passing from the hottest particle is provided in **Figure 7**. Having non-uniform particle distribution significantly reduces the temperature rise of the centered particles. This configuration can be achieved during the coating procedure. The coating procedure can be performed in two steps; first thin coating with high volume density should be applied to ensure low 1D thermal conductivity, higher overall thermal conductivity, and easier thermal pass to the chip. Next, the second coating can be applied by a lower volume density to maximize the light interaction with particles. In another approach, silicone gel can be pressed in the center of the chip to reduce its thickness before forming its final shape.

Table 1 provides the summary of evaluated maximum temperatures and average phosphor temperatures in different coating configurations and LED powers. The average temperature of the particles is also decreased significantly in non-uniform coating. Although the average temperature of the particles in other cases is affected by an intense temperature rise of the centralized particles, non-uniform particle dispersion can ensure lower temperature increases in particles and enhance optical performance and color quality of the PC-LEDs.

Keywords: *PC-LED, Phosphor, Thermal Management, Heat Transfer, Opto-thermal behavior*

EVATEG: EVATEG (Energy Efficient Electronics and Lighting Technologies Research, Development and Demonstration Center) has been established by Prof. Dr. Mehmet ARIK with the initial funds provided by Istanbul Development Agency (ISTKA) at Ozyegin University.

Conclusions

In this research, based on the local self-heating characteristic of phosphor particles in conformal coated Pc-LEDs, their thermal behavior is investigated in particle based thermal simulation. Excessive temperature rises in particles centered over the chip was observed, as also reported in previous studies. The importance of spreading thermal resistance of particles based on their configuration inside the matrix is discussed and confirms the necessity of performing particle based thermal analysis in thermal characterization of Pc-LED, while challenges still exist in experimentally capturing the localized hot spot temperature.

Having high localized temperatures of phosphor in conformal coating is an inevitable issue, as spreading thermal resistance cannot be reduced, even if ideal heat sinks in packages is utilized. However, we have realized that lower thermal conductivity of the host matrix plays an important role herein. It is shown that using a centered higher volumetric concentration of particles reduces the temperature rise of particles. Moreover, using thinner matrices is preferable as lower average temperatures of phosphor particles can be seen in thinner matrices.

These intuitions can lead us to better opto-thermal design of conformal coated PC-LEDs. We suggest that in the center of the chip, a thinner coating with higher volumetric density should be used to minimize the effect of lower thermal conductivity of silicon to provide easier thermal pass for particles. On the other hand, using a thicker matrix in other regions can increase the light scattering probability and ensure the maximized interaction with light rays without a significant increase in the temperature of phosphor particles. ■

Thickness (µm)	α (%)	Erad (W)	Number of Particles	Tmax (°C)	Average Temperature of Particles (°C)
100	9.8	1	2700	120.05	38.47
100	9.8	2	2700	220.1	56.94
100	21.1	1	5808	165.28	47.93
100	21.1	2	5808	310.57	75.87
200	9.8	1	2700	220.23	71.57
200	9.8	2	2700	420.45	123.13
200	21.1	1	5808	332.56	104.38
200	21.1	2	5808	645.13	188.75
100 (non-uniform)	20.9	1	5768	84.207	37.08
100 (non-uniform)	20.9	2	5768	148.41	54.16

Table 1: Summary of evaluated maximum temperatures and average particle temperatures in different configurations.

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DIGITAL PUBLICATION
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PRINT PUBLICATION
JULY 31, 2021

ENQUIRIES | LpR 86
editors@led-professional.com,
info@lugerresearch.com

Imprint

LED professional Review (LpR)
ISSN 1993-890X

Publishing Company
Luger Research e.U. | © 2001-2021
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