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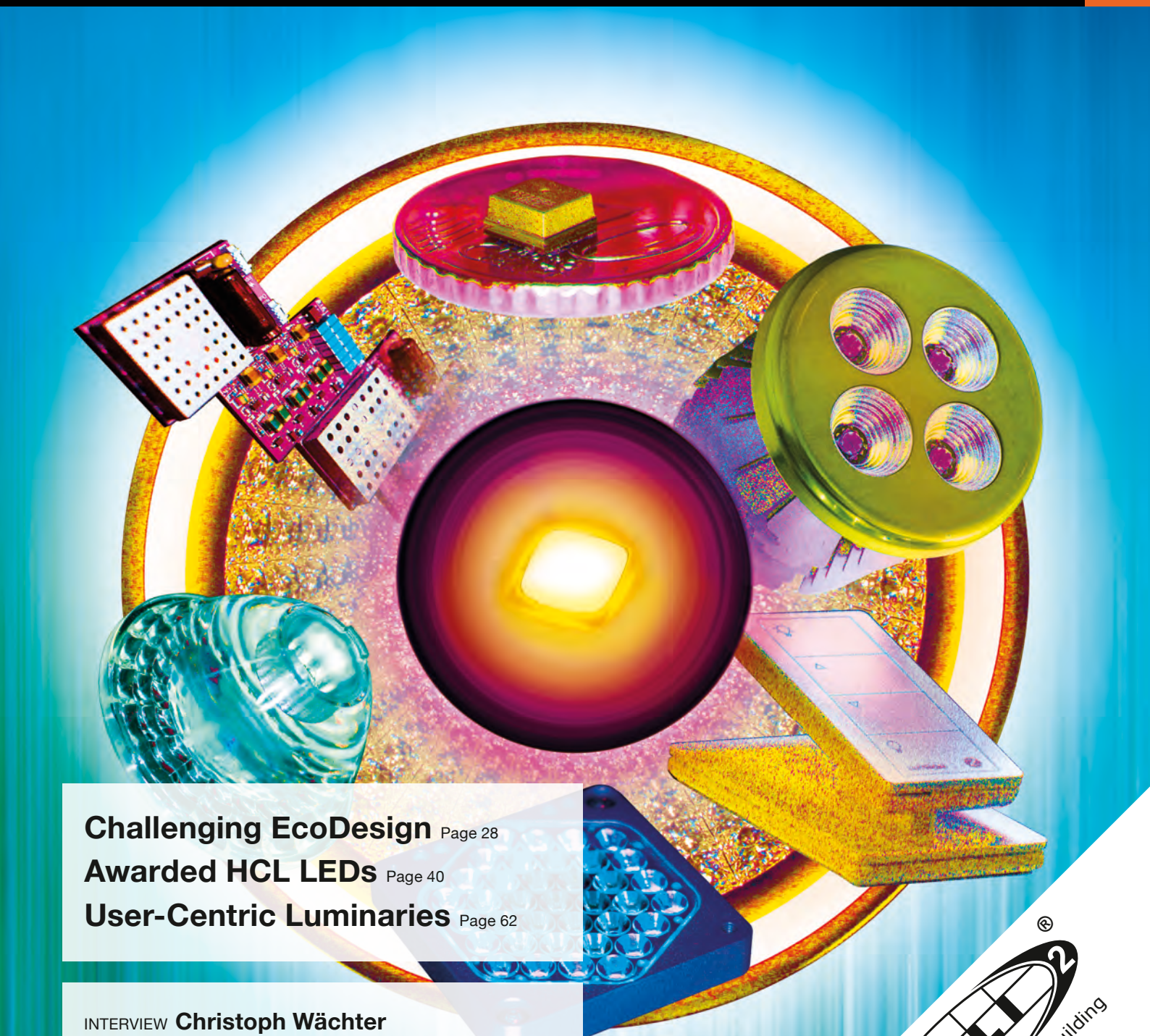

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TECHNOLOGIES **Micro-LEDs & Voice Control**

APPLICATIONS **3D-Printing & Smart Terminals**

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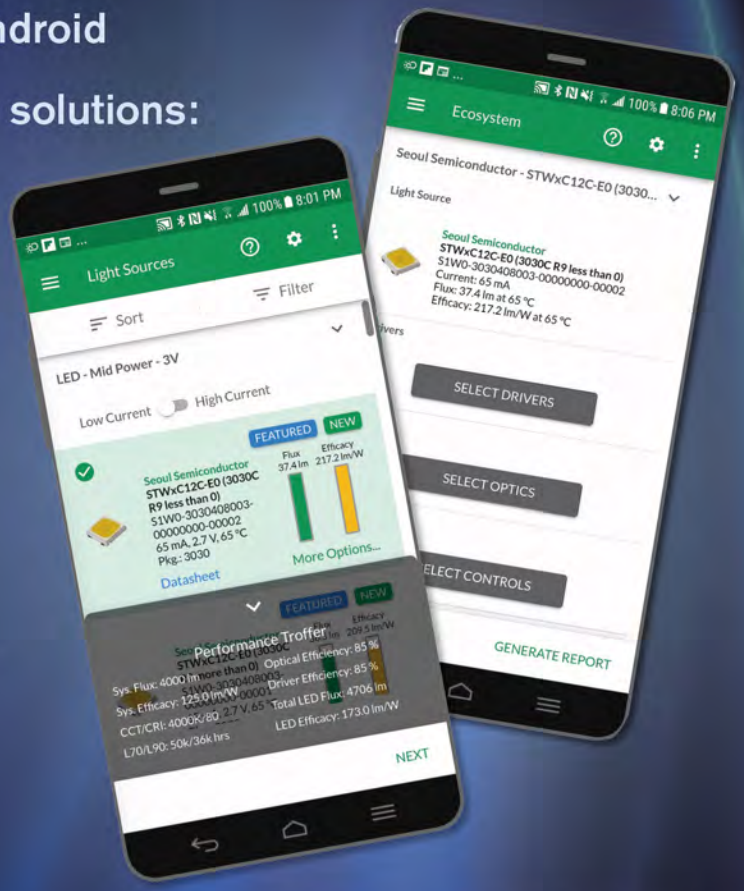

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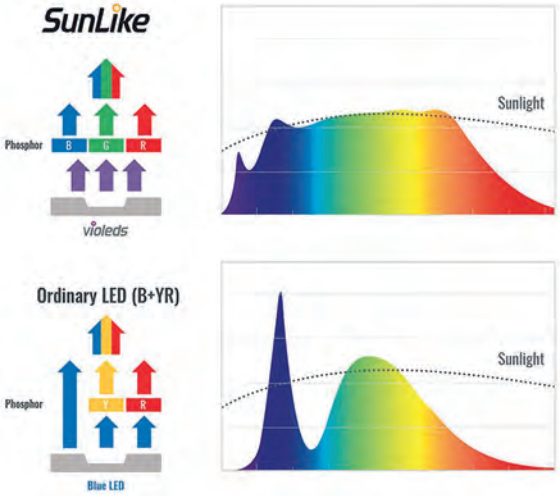

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Light for the Third Industrial Revolution

The third industrial revolution is in full swing, characterized by three major technological advances occurring almost simultaneously: new energy sources, new communication channels and new transport options. Renewable energy sources such as solar energy, wind energy etc., the world of the Internet and IoT and self-propelled traffic on land and in the air show these developments in concrete terms.

The third industrial revolution inevitably goes hand in hand with concrete solutions to protect nature and the environment at its core, to guard our habitat for future generations as well as for ourselves. This is a major challenge. Economic development and sustainability must be closely linked in the future. Applied to the topic of light the question is how and with what the light sector – Photonics – can contribute. From my point of view, the light sector has significant influence on the future development of our planet.

In lighting, the major application areas are Human Centric Lighting, Automotive Lighting, Horticulture Lighting, and UV/IR Applications – all in terms of Internet/IoT networked systems. Miniaturization is currently making a quantum leap with Extreme Ultra Violet Light (EUV) in which future semiconductor structures can be reduced by factors. High-energy pulsed lasers also open up completely new application possibilities. Light, in all its technological and application diversity, holds enormous opportunities and potential. In combination with the development of sustainable systems, we can make a major positive contribution to the future.

We touch on some of these topics in this issue and throughout the year we will also be covering the ones mentioned above.

In closing I'd like to wish all our readers a great start to the New Year. May 2020 be successful for you in all aspects of your lives.

Yours Sincerely,

Siegfried Luger

Luger Research e.U., Founder & CEO
LED professional, Trends in Lighting & Global Lighting Directory
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Fabien Bubendorff, MSc, Dipl. Eng.

Fabien Bubendorff has a Master in Electronic Engineering and has 10 years' experience in the lighting industry. He has spent more than 13 years living in China. He worked as a Product Manager for a Retail Lighting Company, for the last 5 years he was responsible for Wever&Ducré as the Head of R&D in China and for the last years Head of R&D at XAL in Austria.
Now he has founded an independent consultancy to support European Lighting Companies to deal with these future challenges. He specialized in finding the optimal balance between function and cost to increase product profitability.

Paradigm Changes in Lighting

The current era of electronic and software control within the lighting industry is a cause of major disruption, which is pushing many companies to invest heavily in wireless technologies as a form of future insurance against obsolescence. A common problem of adoption is that there is no real industry standardization due to most companies opting to go proprietary to lock-in its customers within their ecosystem. Without the desire to create an open platform, there is too much fragmentation, and most single brands end up failing because of the inability to scale up.

Some non-lighting companies like Silvair, WiZ connected and Casambi are trying to push their systems to the lighting manufacturers in order to provide easier access of connected solutions. However, the transition to wireless systems for lighting manufacturers can still be a burdensome step forward. This requires basic electronic knowledge, proper testing tools, adapted marketing strategies, specific training, and qualified after-sales services. Introducing more electronics into the system creates a new level of complexity for the product and its development. The company's global operations have to be scaled up for the complete product value chain from idea, to development, mass production and sales. Using standard electronic components simplify the value chain, while customization complexifies it. Through design differentiation one can achieve customization with little complexity by adopting some control systems from the non-lighting companies. A tough decision that has to be weighed carefully for each product development cycle.

An example is a recent project where we could not avoid packing the LED driver on a 160 mm diameter ring LED module with a narrow edge width below 12 mm. Recognizing costs, customization efforts, and the right support throughout all levels of the cycle from top management, we found a Chinese partner to be beneficial for this customization. While lighting is not rocket science, without the right partners, it comes with many challenges. But with the proper exposure and understanding of what China can offer, this whole process can be very enlightening and beneficial. This does not mean that such a cooperation has no challenges. However, the experiences demonstrated that the positives outweigh the negatives – provided one is smart in approaching a partnership and manufacturing in China. Europe and North America are still superior in R&D and IP. However, a premium Chinese manufacturer brings together the best of both worlds leading to a "win-win" situation.

China, like every country, has its inferior quality producers and its premium quality producers. Diligent research lets you identify the right partner whose production setup offers a tremendous advantage to the lighting entrepreneur who has not yet made this leap. For those companies or entrepreneurs who used to only assemble in China, there's another game-changing paradigm shift to smart electronics.

To make luminaires compelling and cost effective, one needs a trove of knowledge that has become much harder to acquire. Creating these lighting systems requires more effort. Moreover, cost effective off-the-shelf standard components are becoming scarce, and lighting companies need to be efficient and nimble. Using just in-house resources might not be sufficient. External specialists in optics, design, IoT and electronics, to name a few, should be hired in order to gain access to the wide knowledge necessary to achieve those goals. External collaborations can also be linked to the supply chain to reach more profitable solutions. The combination of external experts coupled with Chinese flexibility and premium manufacturing can produce great results. Shaping a well thought lighting modular platform to attain a good level of customization while keeping the advantages of an Asian supply chain and Western IP, is a keystone to success. ■

F.B.

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Target Applications

- Office
- Education
- Retail

For the latest information on Signify products contact your local FLS sales representative.

Fortimo InstantFit has been accepted into the 2019 IES Progress Report, recognizing it as a unique and significant advancement to the art and science of lighting

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2019 PROGRESS Report SELECTION

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APPOINTMENTS

The Global Lighting Association Elects New Executive Committee, Foreshadowing Active Advocacy Programs

The Global Lighting Association (GLA) met early December in Tokyo and elected an inaugural Executive Committee in anticipation of its incorporation as a non-profit association in Switzerland. Completion of the incorporation process is expected early in 2020. **Maurice Maes**, as a representative of LightingEurope, was appointed President.

He is employed by Signify, formerly known as Philips Lighting, as Head of Standards & Regulations. Reflecting a commitment to increase activities in support of the global lighting industry, the GLA elected two Vice Presidents to assist with the anticipated additional workload. They are Chen Yansheng, President of China Association of Lighting Industry and Pekka Hakkarainen, representing the National Electrical Manufacturers Association in the United States. Michael Ng from the Taiwan Lighting Fixtures Export Association was elected Treasurer.

"The time is now for the GLA to enable and promote, at a global level, the full potential of modern lighting to enhance human well-being alongside sustainability goals," said Maurice Maes, "and this can only be done by the GLA taking an active role in harmonizing and ensuring better enforcement of regulations and standards across the globe."

The GLA today represents over 25 regional and national lighting trade associations, collectively representing over 5000 lighting manufacturers, and the association looks forward to welcoming new members to participate in the next phase of its journey. ■

Elektra Lighting Appoints New Design Director

Congratulations to **Magdalena Gomez** who has recently been appointed Design Director at Elektra Lighting. She has worked at Elektra since 2013 and originally trained as an architect specializing in Urban Planning in Mexico. Later, she completed her Masters in Architectural Lighting in Germany where she transitioned into Lighting Design.

Her passion and drive for lighting infuses her projects and takes her across the globe. Many of her projects have received numerous international accolades including the UK Lighting Design Awards in the Hospitality category. Magdalena enjoys the diversity Elektra's projects offer and is relentlessly seeking new knowledge and sources of inspiration. When asked what she is looking forward to most she said "I love new challenges and being able to share my experience with others." ■

Guillermo de Peñaranda New TRILUX CEO

Guillermo de Peñaranda steps up to CEO at TRILUX after being a member of the TRILUX Management Board since April 2019.

He has almost twenty years of experience in the international management of successful German industrial groups such as Thyssenkrupp and Bosch and, as the new CEO, will be responsible for the strategic alignment of the TRILUX Group. "With our strategic core themes of digitalization, internationalization and our customer centric approach we create the perfect conditions for TRILUX to develop into a strong global player within a dynamic market," said de Peñaranda about his areas of responsibility.
A company-wide change process will make this realignment both visible and tangible at all levels as well as successfully implementing it long term into the company.

Dietmar Zembrot, Chief Technological Officer for many years left TRILUX in September 2019. Mr. Zembrot, as CTO since 2008, has been responsible for Research, Development and Product Management and has made a decisive contribution to the technological development of TRILUX in recent years. "With his many years of experience and expertise Dietmar Zembrot has played a significant role in the successful development of the TRILUX Group. Under his leadership we have successfully completed the transformation to LED. We have established our technological leadership with the founding of the ITZ, and have systematically further developed it until today," explained Michael Huber. ■

LEDiL Makes Key Leadership Changes

Finnish LED secondary optics specialists make key changes to the leadership team. **Petteri Saarinen (right)** has been appointed as the new CEO of LEDiL, Petteri Saarinen has more than 20 years of operational and international experience within several different companies. His most recent position was in the Finnish inductive energy solutions firm Trafotek.

"I would like to thank Rami Huovinen, one of LEDiL's co-owners and Board members, who has successfully managed LEDiL as interim CEO and look forward to welcome Petteri onboard. With his previous experience of international business, proven leadership and business acumen, Petteri will lead LEDiL back to profitable growth and continued international expansion," says Jonas Wiström, CEO of Ratos and Business Area President Industry. Juha Päivärinta has been appointed new Business Director at LEDiL. Juha has many years of experience in the lighting and technology industry having worked for Hella Lighting Finland, M. Haloila Oy, Porsche Leipzig and Valmet Automotive in sales, product and project management roles.

"I am a hands-on kind of guy who likes it when things are structured and run smoothly", Juha says. He continues, "I'm an inventor at heart, but also a realist that keeps his feet on the ground." As a team leader Juha believes in fairness and inclusivity. All team members and their particular skill sets are important for solving the tasks at hand. He believes some tasks are best handled within the team while others are better solved by concentrating alone in peace and quiet; but Juha promises his door is always open. ■

BDP Welcome New Architect Director In Rotterdam

BDP has appointed **Björn Bleumink** as architect director to lead its Rotterdam studio. With over twenty years of experience at internationally renowned design practices including Mecanoo architecten, KCAP architects and planners and DP6 architectuurstudio, Björn has a long track record of architectural and masterplanning

projects across the housing, leisure, education and healthcare sector. Amongst the projects he has worked on are the first earthquake proof educational building constructed in The Netherlands and the masterplan for the housing led regeneration of Abbey Wood and South Thamesmead in London.

Björn said: "I'm delighted to be joining the BDP team at what is a very exciting time for the practice. BDP's vision for creating well-designed and human centred buildings and neighbourhoods provides a solid context for strong and vibrant communities. I look forward to contributing to that vision as it fits seamlessly into the Dutch architectural and urban design tradition." John McManus said: "We are delighted to welcome Björn to BDP. His expertise and successful track record, coupled with his strong collaborative approach, will be a great asset to the practice and contribute enormously to its growth particularly in The Netherlands and across Europe."

BDP established its Dutch studio in 2008. The studio moved to Rotterdam in 2016 and comprises architects, landscape architects, urban planners and urban designers. ■

Light Bureau Appoint Christopher Seider To Global Business Development Role

Christopher Seider joins award-winning lighting design and consulting agency Light Bureau, formerly ÅF Lighting and part of the AFRY group. Light Bureau is a global market leader in the professional lighting design industry, collecting accolades for many projects worldwide.

Mr Seider joins a multidisciplinary lighting department of over 100 dedicated employees including; designers, architects, engineers, planners, experts in art and cultural history, 3D specialists and experts in economy and communication.

This diversified group offers an exceptionally broad range of services and competencies, balancing functionality, aesthetics and sustainability. This approach cannot be demonstrated more aptly than at Under, the restaurant five and a half metres below the surface in Norway, exposing the wonders beneath the sea using Liquid Light®.

Under recently won the Norwegian Lighting Award in the indoor category for the lighting concept. During more than two decades in the lighting industry, Christopher Seider ran the consultancy agencies Seider Design and Integrated Innovation & Design, and notably developed renowned brands including, Zumtobel Group as Executive Vice President, along with working in award winning offices Lichtvision in Berlin, and Fisher Marantz Stone in New York.
This exciting new chapter at Light Bureau will no doubt bring together a fierce wealth of lighting design and brand knowledge at one of the largest lighting design offices in the world.

Today the AFRY Group has more than 17,000 employees with a presence in more than 50 countries. AFRY is an engineering and design company within the fields of energy, industry and infrastructure. ■

Lionel Brunet Elected President Of LightingEurope

The LightingEurope Executive Board has elected Mr **Lionel Brunet** as President of LightingEurope, for a 2 year term.
Mr Brunet is 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. "I am honoured to be elected President and look forward to working with the Executive Board for all LightingEurope members to deliver our strategic vision and priorities for Better Lighting for all," says Mr Lionel Brunet.

The General Assembly elected a new Executive Board. Details about the members of the Board can be found here.

The LightingEurope General Assembly also adopted new priorities for 2019–2021 to ensure the organization remains on track to achieve the lighting industry's strategic roadmap for 2025. LightingEurope will promote simple rules and will focus on

better enforcement, delivering the value of lighting, implementing circular economy thinking and shaping EU legislation impacting lighting. ■

Casambi Appoints Kari Mettälä New CEO

Casambi established in 2011 has become a key pioneer in wireless lighting controls based on Bluetooth Low Energy (BLE). **Kari Mettälä (right)** now serves as Chief Executive Officer (CEO), a move instigated by Founder Timo Pakkala, Casambi's former CEO, who continues with the company in a product management role.

Previously Chief Operations Officer at Casambi, Kari Mettälä has a proven track record of success in international business development. With over 25 years of experience in senior management and consultancy, Kari has demonstrated his talent for driving long-term top-line revenues, expanding operations profitably and delivering product innovation. Besides serving as CEO for over a decade for a leading provider of directional audio solutions, he also has previous management experience working within the consulting and professional audio-visual sector.

Kari Mettälä commented: "I'm delighted to be appointed as CEO of Casambi and to lead our multi-award-winning company to even greater success. Together with Co-Founder Elena Lehtimäki, Timo Pakkala has transformed Casambi within a decade from a start-up to a business widely acknowledged to be the world's leading wireless lighting control platform. With his ongoing support, I am confident we will build on this solid foundation and strengthen our brand's leadership position." Timo Pakkala will focus on product management of Casambi's unique complete end-to-end solution that serves all stakeholders and all phases of a lighting project. The company's goal is to provide the best possible user experience for all the stakeholders at all phases of a lighting design: from the integration of Casambi technology designed into ecosystem partner products and project specification to ease of commissioning and the interface experienced by end customers.

Timo Pakkala said: "The Casambi brand continues to establish its technology platform as the de facto standard for lighting control. We plan to steadfastly accelerate growth of the business by delivering the ultimate user experience for lighting professionals while raising loyalty among our partners, customers and other stakeholders. Our management refocus is hugely positive with the cornerstones of our technology and the core benefits of creating an optimal solution in terms of ease of installation and functionality with minimal additional hardware and deployment costs remaining intact."

Casambi's management team is committed to promoting the growing ecosystem of 'Casambi ready' luminaires and control devices available in the lighting market, and to boosting collaborations with industry partners and lighting professionals across the world. ■

REGULATIONS & ORGANIZATIONS

CIE Announces Availability of New Documentation: Test Method for OLED Luminaires and OLED Light Sources

The new CIE International Standard S 025-SP1/E:2019 is a supplement to CIE S 025:2015 Test Method for LED Lamps, LED Luminaires and LED Modules specifies the requirements for measurement of electrical, photometric, and colorimetric quantities of OLED luminaires and OLED light sources. These sources were not covered by CIE S 025:2015 even though they are very similar in regard to the measurement techniques. Recent improvements in the technology and availability of OLED-based lighting products raised the necessity to extend CIE S 025:2015 to OLED products.

Comparable measurement results for OLEDs have become more crucial during the last years. CIE's latest supplement to CIE S 025:2015 Test Method, the CIE International Standard S 025-SP1/E:2019 accommodates this request

OLED luminaires and OLED light sources offer a large variety of configurations with respect to geometry and/or color. The electrical, photometric and colorimetric performance of these devices need to be determined for each configuration unless it can be shown that a given configuration has equivalent performance to another.

The relevant clauses of CIE S 025:2015 are considered in terms of their applicability to measurement of OLED luminaires and OLED light sources and, where required, specific requirements are given. For measurements of LED lamps, LED luminaires and LED modules, the requirements of CIE S 025:2015 remain unchanged.

The document aims in particular to cover measurement methods for testing the compliance of OLED light sources and OLED luminaires with the photometric and colorimetric requirements of OLED performance standards issued by IEC/TC 34 "Lamps and related equipment", in particular IEC 62922. This CIE International Standard has been approved by the CIE National Committees. It is readily available from the CIE Webshop or from the National Committees of the CIE. Price of this CIE International Standard: EUR 72, – (Members of a National Committee of the CIE receive a 66,7% discount on this price – please approach your NC for information on accessing this discount).

About the CIE:

The International Commission on Illumination – also known as the CIE from its French title, the Commission Internationale de l'Eclairage – is devoted to worldwide cooperation and the exchange of information on all matters relating to the science and art of light and lighting, color and vision, photobiology and image technology. With strong technical, scientific and cultural foundations, the CIE is an independent, non-profit organization that serves member countries on a voluntary basis. Since its inception in 1913, has been accepted as representing the best authority on the subject and as such is recognized by ISO as an international standardization body.

For any further information please contact CIE Central Bureau, Kathryn Nield, General Secretary, at Babenbergerstraße 9/9A, A-1010 Vienna, Austria, by phone at +43 1 714 31 87 or by email at kathryn.nield@cie.co.at. You may also visit the CIE website at http:/www.cie.co.at ■

New Regulations on Ecodesign and Energy Labeling Impact Lighting Products – LightingEurope Guidelines Available

The European Commission has published Regulation (EU) 2019/2020 on ecodesign requirements for lighting and Regulation (EU) 2019/2015 on energy labeling for lighting which will apply in all EU Member States from September 2021. LightingEurope has

prepared guidelines to help companies comply.

The two regulations published in the Official Journal of the European Union bring major changes for producers and end-users of lighting products.

New in the energy labeling regulation (ELR) are the enlargement of the scope to all light sources placed on the EU market, the rescaling of the energy label for lamps to the well-known energy labeling scale A–G, and the discontinuation of the energy label for luminaires. The ELR also clarifies the new requirements for registering light sources in the EPREL database from May 2021 onwards.

The EC Ecodesign and Energy Labeling regulations are not just used within the EC but many other countries worldwide align their regulations to it

The ecodesign regulation for light sources, also known as the Single Lighting Regulation (SLR) because it combines requirements that today are set out in three separate pieces of legislation, introduces fundamental changes, such as energy efficiency requirements that over the next few years will ban T8 linear fluorescent lamps and compact fluorescent lamps with integrated control gear. Most of the currently remaining halogen lamps continue to be allowed on the EU market. The ecodesign rules also include circular economy requirements, for example, on the removability and replaceability of light sources and control gears contained in products.

LightingEurope has worked closely with regulators on both laws and the guidelines build on our experience and outline our recommendations on how the rules should be understood. "The LightingEurope guidelines on the new ecodesign and energy labeling rules are our contribution to make sure that all companies can understand and apply these new and complex rules, and that all authorities can enforce them," states Ourania Georgoutsakou, LightingEurope Secretary General. "LightingEurope has been involved in drafting and debating these laws over the past five years, contributing our industry's technical expertise and market reality. We will now turn our focus to supporting our members, with webinars and separate guidelines on how to comply with EPREL (the EU energy labeling database) obligations and to educating companies from across the world and Europe's market surveillance authorities on how to apply these new rules and deliver quality products for people and a level playing field for the industry," she adds.

The new LightingEurope guidelines are available to view and download at https://www.europeanlightingprioritiies.eu/guidelines.php

More information is available at www.lightingeurope.org

For further information, please contact:
Ourania Georgoutsakou, Secretary General, LightingEurope,
ourania.georgoutsakou@lightingeurope.org

About LightingEurope

LightingEurope is the voice of the lighting industry, based in Brussels and representing 34 companies and national associations. Together these members account for over 1,000 European companies, a majority of which are small or medium-sized. They represent a total European workforce of over 100,000 people and an annual turnover exceeding 20 billion euro. LightingEurope is committed to promoting efficient lighting that benefits human comfort, safety and well-being, and the environment. LightingEurope advocates a positive business and regulatory environment to foster fair competition and growth for the European lighting industry. ■

DiiA Starts D4i Certification of LED Drivers

D4i certification brings standardization to intra-luminaire DALI, and enables intelligent, data-rich LED luminaires that can interact with external lighting-control networks.

The Digital Illumination Interface Alliance (DiiA), the global industry organization for DALI lighting control, has started its D4i certification program. D4i brings standardization to intra-luminaire DALI, and extends the existing DALI-2 program by adding a specific set of new features that create new possibilities for DALI in the IoT world. By specifying power-supply requirements and smart-data capabilities, D4i enables intelligent, connected, future-proofed LED luminaires.

DiiA starts D4i certification of LED drivers

Intra-luminaire DALI refers to a small DALI network inside an individual luminaire. D4i specifications ensure that power is available for control devices – such as sensors or wireless communication devices – that are attached to or integrated into the luminaire. D4i-certified LED drivers have an integrated DALI bus power supply, providing power to the DALI bus and to some control devices. In addition, D4i for outdoor luminaires includes auxiliary 24 V power supplies for devices with higher power requirements, such as city-wide transceivers. D4i also enables intelligent luminaires by standardizing the storage and reporting of data relating to the driver, light source and luminaire. The bi-directional nature of DALI enables such data to be communicated with the lighting-control network. Data stored within the driver can be used for enhanced asset tracking, as well as performance monitoring, diagnostics and energy metering.

More information on D4i and the individual power and data specifications can be found on the DiiA website: www.dali2.org/d4i.

DiiA members are now able to certify their D4i LED drivers in a procedure that includes independent verification of test results. Certified products are eligible to carry the new D4i logo, a DiiA trademark which indicates interoperability. The D4i logo trademark can also be used on qualifying luminaires.

D4i certification is also available for stand-alone 24 V auxiliary (AUX) power supplies. Control devices – such as sensors and wireless communication devices with a DALI gateway – will be added to the D4i certification program at a later date.
All D4i-certified products are listed in the online Product Database.

D4i is aligned with the new ANSI C137.4 standard, and is also compatible with socketed connector systems such as NEMA/ANSI C136.41 and Zhaga Book 18. DiiA and Zhaga are working closely together and have developed the joint Zhaga-D4i certification program for outdoor D4i luminaires that have a Zhaga socket. ■

MD-SIG Integrates Into the Zhaga Consortium

Zhaga and MD-SIG are pleased to announce that they have agreed to align their efforts and to proceed as a single organization under the Zhaga Consortium. Zhaga members have access to the former MD-SIG specifications as part of their Zhaga membership.
The Module-Driver Interface Special Interest Group (MD-SIG) is a global lighting industry consortium, with the aim to introduce standardized multi-vendor electrical interfaces between LED control gear and modules as the missing link essential to the maturity of SSL components business. The Zhaga Consortium is a global association of lighting companies that is standardizing interfaces of components of LED luminaires.

Increasingly, NFC is being used in the lighting industry. MD-SIG addresses standardization of smart electrical interface between LED control gear and modules and now joins forces with Zhaga

In spring 2019, the Zhaga Consortium and the MD-SIG entered into a dialogue to explore the possibility of aligning their standardization activities. In summer 2019 the organizations agreed that it was best to harmonize their efforts. Following the decision to integrate MD-SIG into Zhaga, MD-SIG has started operating as a Zhaga Working Group per October 2019. Participation in this Working Group and access to its deliverables is henceforward arranged via Zhaga membership.

"MD-SIG members have been very successful in their standardization work," says Dee Denteneer, Secretary General of the Zhaga Consortium. "The integration will bring a clearer and stronger voice to the market and we look forward to promote their specifications globally under the Zhaga brand. The integration also brings a new set of competences to the Zhaga Consortium, enabling Zhaga to even better deliver on its interoperability promise."

As part of the integration, the MD-SIG specifications have been adopted as Zhaga specifications:

- Zhaga Book 24: "NFC programming interface", specifying a digital, wireless programming approach using near-field communication (NFC)
- Zhaga Book 23: "LEDset information interface" describing an analogue interface allowing basic communication between an LED control gear and one or more LED modules
- Zhaga Book 22: "LEDset power interface" describing driving capabilities like voltage, current and power ranges of LED control gears and respective LED module operating requirements

Because of the integration, Regular and Associate Members of the Zhaga Consortium have immediate access to the MD-SIG specifications as Zhaga Books 22, 23, and 24; the LEDset power and information interface specifications were already published and continue to be available through Zhaga, via the Community Membership, as Books 22 and 23.

About MD-SIG:

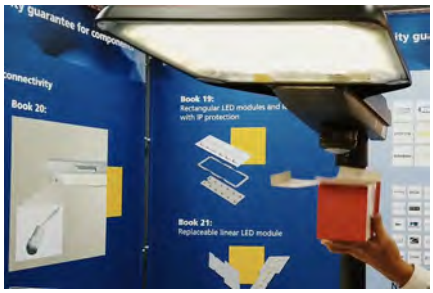
The Module-Driver Interface Special Interest Group (MD-SIG) is a global lighting industry consortium aiming to introduce a standardized multi-vendor electrical interface. Member companies are BAG, BJB, Helvar, OSRAM, Panasonic/Vossloh Schwabe, Signify, TCI and Zumtobel/Tridonic. – md-sig.org

About Zhaga:

Zhaga is a global association of lighting companies that is standardizing interfaces of components of LED luminaires, including LED light engines, LED modules, LED arrays, holders, electronic control gear (LED drivers) and connectivity fit systems. This helps to streamline the LED lighting supply chain, and to simplify LED luminaire design and manufacturing. Zhaga continues to develop specifications based on the inter-related themes of interoperable components, smart and connected lighting, and serviceable luminaires. – www.zhagastandard.org ■

Zhaga Book 18 Ed. 2.0 Has Been Published

Zhaga member companies can now access the specification and certify luminaires according to the Zhaga-D4i certification program. Dekra and Intertek are the accredited test centres.



Zhaga Book 18 Ed 2.0 specifies the mechanical, electrical and communication interfaces between luminaires and sensors and/or communication modules. This includes details for a solution with two modules.

Book 18 Ed. 2.0 brings together complementary specifications from the Zhaga Consortium and the D4i specifications from the Digital Illumination Interface Alliance (DiiA). Zhaga and DiiA have collaborated to achieve true plug-and-play interoperability, a strong benefit for specifiers, purchasers, installers and end users.

Plug-and-play, socket-based connectivity system makes it easy to add or upgrade sensors and/or communication modules, which in turn enables luminaires to keep pace with rapid developments in digital networking and sensing technology while module makers can continue to innovate and diversify using an open global interface standard.
By replacing the module rather than the entire luminaire, the luminaire is future-proofed, an essential requirement in Smart City lighting.

The new Zhaga-D4i certification is available for LED luminaires that have a powered Zhaga Book 18 receptacle and use LED control gears meeting the D4i requirements. Luminaires can now be certified by Dekra and Intertek, as the Zhaga accredited test centers. Luminaire OEMs intending to develop products for Zhaga-D4i certification benefit from the availability of Zhaga-certified receptacles and D4i-certified LED control gears from a number of vendors. The certification of Zhaga-D4i modules, i.e. sensors and/or communication devices with a Zhaga Book 18 plug and D4i compatibility, is expected to open in Q1 2020. More information on the Zhaga-D4i certification program is available in an article in the May/June issue of LED Professional Review (see the article). Zhaga Book 18 Ed. 2.0 is available to Zhaga's Regular and Associate members. ■

SOLID STATE LIGHTING

Lumileds Boosts Intensity of CoBs for Spotlights and Downlights

Lumileds introduced three lines of CoBs: the LUXEON CX Plus CoB (Gen 2), LUXEON CX Plus CoB – High Density and LUXEON CX Plus CoB – High Density (Below BBL), drop-in upgrades for Lumileds and competing arrays. The second-generation arrays feature industry leading performance and a 14% flux improvement vs. the previous generation. Delivered in a range of light emitting surfaces (LES) (4.5, 6, 12 and 14 mm) and correlated color temperatures of 2700 K to 5000 K, the Gen 2 arrays provide excellent efficiency of above 140 lm/W at 3000 K 80 CRI or 122 lm/W at 3000 K 90 CRI.

The High-Density version of LUXEON CX Plus CoB provides industry leading punch (center beam candle power) and is available in on-black body locus (BBL) coordinates for halogen-like illumination or below-BBL for ceramic metal halide-like illumination.

The LUXEON CX Plus CoB – High Density provides up to 1,150 lumens at 3000 K 90 CRI from the smallest LES of 4.5 mm. Flux is 10% higher than competing CoBs at 6 mm and

9 mm LES. Offered in three LES (4.5, 6 and 9 mm) on 13.35 × 13.35 mm substrate, the arrays cover a range of color temperatures (2700 K to 5000 K) with a minimum of 80 CRI or 90 CRI and color control within 3-step or 2-step MacAdam ellipse.

Lumileds new CoBs feature brilliant light with greater punch, efficacy and reliability than competing products, the LUXEON CX Plus CoBs enable exceptional spotlights, track lights and PAR lamps

For the Below-BBL versions, color temperature range is 2700 K to 4000 K at a minimum of 95 CRI with color control within 3-step or 2-step MacAdam ellipse.
"The below black body option is perfect for illuminating artwork, for instance, because the highest color fidelity combines with slightly more saturated colors for stunning results," said LP Liew, Product Manager of LUXEON CoBs.

All LUXEON arrays utilize a metal core PCB substrate that is more resistant to cracking during luminaire assembly. The low resistance of the MCPCB also provides superior removal of heat from the LED, leading to smaller heatsinks and more compact luminaires. ■

Signify Launches – Tailor Luminaires Online & Let It 3D Print

Signify announced the world's first service for consumers that allows to tailor and order luminaire (lamp shade and light) online, have it 3D printed from recyclable material and delivered to the door within two weeks. The company also announced it is using recycled material to 3D print with, starting with used CDs, and launched a Philips-branded LED table lamp made from 24 recycled CDs.

Following a pilot project in the Benelux, Signify is expanding its consumer service across Europe. With just a few clicks you can design your own decorative luminaire. Simply select your base design, then personalize it, choosing the size, color, texture and pattern of the luminaire and the type of LED bulb, including Philips Hue bulbs. Signify delivers the finished product to your door within two weeks.

Signify's 3D printed luminaires are built with sustainability in mind. The base material is a polycarbonate that is strong, high-quality and 100% recyclable. A typical manufactured luminaire, excluding the electronics and bulb, has a 47% lower carbon footprint than a traditionally built metal luminaire. Furthermore, no glue is used and they have fewer parts. They are two-thirds of the weight of a conventional luminaire, which translates to a 35% carbon emission saving when shipping.

Signify's investment in 3D printing further illustrates the company's commitment to better serving its customers while reducing their, and its own, carbon footprint.
"This is the first mass-market service that allows you to tailor your own sustainable lighting aesthetic. And being online, it could easily be integrated into third-party web stores giving consumers more choice," said Khalid Aziz, Head of Ventures at Signify. "It's another world first in lighting and illustrates how we lead the way in serving customers all over the world with the most innovative and sustainable lighting technologies."

Signify launches world's first service that lets one tailor luminaires online and then 3D prints and delivers them to the home

Printing from recycled CDs

Signify has also started using polycarbonate string made from recycled material. The first product to use it is a Philips LED table lamp which uses 24 recycled CDs in its construction. Available from November 28, 2019, it costs EUR 99 and can be ordered from https://www.mycreation.lighting.philips.com. In the course of next year, Signify expects that all its 3D printed products will be available using recycled material.

"Philips and Sony introduced the CD to the world in the early 1980s. Today, we're honoring that legacy by creating high-quality, beautiful decorative lamps by reusing this iconic technology," added Aziz.

Signify also unveiled major international expansion plans for 3D printing bespoke and tailored luminaires for professional customers. The professional products can be recycled at their end of life. In 2018, 79% of Signify's sales comprised sustainable revenues.
The company is committed to be carbon neutral in 2020 and was recently named Industry Leader in the Dow Jones Sustainability Index for the third year in a row. ■

Acuity Brands Introduces the Renna Rectilinear Luminaires from Peerless for Architectural Spaces

Acuity Brands, Inc. introduced Renna™ luminaires from Peerless®, an innovation in rectilinear lighting combining superior technology in a sleek minimalist design for complementing architectural or commercial spaces. The luminaire earned top recognition from the LFI Innovation Awards® in 2019, one of the lighting industry's most prestigious award programs, for overall Design Excellence and Best of Category for Commercial Indoor.

"We are excited to launch Renna luminaires from Peerless, adding more design, control and connectivity options to a renowned architectural lighting brand," said Tim O'Brien, Acuity Brands Lighting Vice President and General Manager Architectural Business Unit. "Renna luminaires are flexible, scalable and include emergency lighting support options. Renna provides a minimalist design with profiles 4 inches wide by 1 inch high. It can deliver desired lighting levels while providing a combination of independent uplight, downlight, task and wall washing illumination."

Renna provides direct, indirect, or bidirectional illumination of a space without the concentrated light distribution common to smaller LED luminaires. Its batwing distribution spreads the light uniformly across a surface, which minimizes the quantity of fixtures required for installations. The precisely molded optics on each LED and the LED board allow for accurate direction and distribution of light output. True to other Peerless luminaires, Renna includes optics that help make lit spaces visually comfortable for people. Additionally, Renna luminaires include seamless controls integration.

Acuity Brands new Renna Rectilinear luminaires feature the Modulus™ low voltage distributed power and control system

Renna luminaires feature the Modulus™ low voltage distributed power and control system. The Modulus system uses a single unit for powering a luminaire run of up to 32 feet versus requiring a unit every eight feet, which reduces the total cost of ownership.

With fewer connections and drops, designing electrical layouts will be simpler, and specifying engineers and contractors will experience easier configuration and installation, which can reduce installation costs. Within the design layout, a row of luminaires or specific sections can be selected for emergency lighting while running conduit through a single unit.

"There's a market need for ever smaller, unobtrusive luminaires like Renna that can be used for creating expansive designs in spaces. However, these small luminaire form factors make it difficult to embed existing technology due to spatial constraints," said Gilles Abrahamse, Vice President Digital Luminaire Components. "Renna is able to leverage Modulus to provide power and control for its minimal form factor of one inch in depth." For more than 125 years, Peerless has created elegant, technology-driven luminaries that enhance the user's experience. Renna luminaires continue that legacy with premium quality in a cost-effective solution. ■

Amerlux Expands Linea Line with Adjustable Accents

Amerlux, an award-winning design-and-manufacture lighting company, announced the expansion of its linear lighting family with new solutions that will deliver more options for architects and lighting designers.

Streamlined and flexible, the Linea LED pendants provide the freedom to create dynamic spaces with aesthetics, performance and energy efficiency. The Linea 1.5" Direct Distribution with integrated adjustable accents offers cable-suspension or surface-direct installation, while the Linea 2.5" Direct with adjustable accents and the Linea 2.5" Direct/Indirect with integrated adjustable accents provide flush-mount or surface-mount options.

Pendant-mounted for spaces with or without ceilings, Linea provides linear run lengths for general lighting over desks and conference tables or individual standard lengths over a reception area. It provides warm and cool light in 2700 K, 3000 K, 3500 K (industry standard) or 4000 K.

"Like the rest of the product family, the new four Linea solutions deliver more design options to spaces that require elegance and beauty," said Bill Plageman, who is Amerlux's VP of Marketing. "They deliver the right amount of lighting with the best energy and maintenance savings for rapid ROI. Their lumen output does not begin to depreciate until after 50,000 hours of use, compared to 100 hours of use for fluorescent lamps." Linea products, which come with a five-year warranty, offer such a long lifespan that maintenance costs are significantly reduced. In addition, the fixture is extremely energy efficient, providing power cost savings. Standard Linea products can ship in 10 days or less from the time they are ordered to quickly advance any new construction or retrofit project.

In addition to expanding the line of Linea, Amerlux has recently launched other innovative solutions to address several pain points.

Amerlux's New Linea Line solutions also add flush mounts for even more design flexibility

Snap In-and-Out Lighting for Any Room

Amerlux's Slots and Dots is an easily configurable track light system that creates visual ambience for high-end residential, hotels, restaurants and commercial space. The new lighting solution gives designers the ability to add visual elements, as well as the ability to move them at will.

Amerlux's Slots and Dots offers clean, compact styling, which ensures it looks good in any environment. The one-inch-wide track features magnetic attachments, so light sources can be easily snapped in and out as needed. With this track system, it's a cinch to change the lighting in a room between events. In fact, lighting elements within the track system can be moved without the need for an electrician.

The light attachments include accent track heads, a pendant accent and four different linear options, with lensed sources for ambient light and high-performance optics for direct light. The four linear options include: Opal (glow), MicroPrism (general illumination), Comfort (light on target with minimal glare) and 30 deg (directional light with 30-degree beam). The track is available in variable lengths and field cuttable to fit any design or run length.

In addition, the track is offered in four different styles for more options:

- Deep recessed track for flush mounting of linear lighting elements
- Shallow recessed track for surface-mount appearance of lighting elements only
- Deep Surface/Pendant track to visually see

the track with linear lighting elements fully recessed
- Surface Shallow track for use when linear lighting elements are desired to be seen

Speedy Installation for Contractors

Amerlux's new Quick-Line Recessed 4" Linear is an architectural-grade LED fixture that delivers on the promise of speed, low cost and high quality, while adding another design option. Sold in middle-of-run segments, Quick-Line is stocked on the shelf in standard lengths, standard color temperatures and standard lumens per watt, which allows the product to ship in as little as 72 hours.

Quick-Line Pendant 1.5" offers an LED architectural-grade fixture that delivers on the same promise of speed, low cost and high quality. In fact, Amerlux's engineering has essentially turned the installation process into an ad jingle: Link it, Latch it, Cap it. The pendant solution ships – in as little as 72 hours – with the lenses and LED boards installed with no need to remove in order to install. The pendant solution offers a 1.5" aperture, performance lens and an end cap light-block shield to prevent light leakage, which occurs when the lens shrinks and creates a gap between the end cap and lens.

Flexible Lighting for Evolving Supermarkets, Retail

Amerlux's Cadence allows stores to easily change the location of the light source without the help of an electrician. In addition, the lighting system's attachments snap in and out. As online competition and dollar stores capture more dry-goods business, supermarkets need a lighting solution that allows them to accommodate the shrinking aisles that will make way for more featured fresh food. Cadence provides batwing aisle distribution, focused open-case distribution, general ambience distribution and a track lighting section that incorporates accent lighting to create heightened attention for high-margin products.

In addition, Cadence features a unique trunking system that is pre-wired with two circuits, as well as an emergency circuit – right out of the box. Installation is easy: Simply connect power to one end of the trunking system, add sections with quick connects and then add lighting modules. Besides supermarket aisles, Cadence can exceed expectations for any open-style retailer. The innovative lighting solution moves, thanks to the trunking system, which allows stores to easily change their lighting to highlight fleeting specials or sales items. ■

Instrument System's New Spectroradiometer Speeds up LED Production

Product life cycles are getting shorter all the time. The corresponding increase in the number of product variants presents manufacturing companies with new challenges. Production lines need to be faster and more complex, yet also more user-friendly. Instrument Systems – a well-known manufacturer of light measurement technology – works closely with its customers in the field of LED production to develop modular and flexible components for quality inspection in mass production environments. For the new spectroradiometer CAS 125, Instrument Systems has therefore focused on production-related applications for LEDs in the spectral range between 200 and 1100 nm. Instrument Systems will be presenting its new measurement device at booth 8.0 F60 of next year's Light + Building trade show, which will be held in Frankfurt from 8 to 13 March, 2020.

Instrument System's CAS 125 spectroradiometer with CMOS sensor has been optimized for applications in production environments

The new CAS 125 spectroradiometer with CMOS sensor is designed to maximize production efficiency and offers a unique "Recipe" mode that enables time-optimized control: For the CAS 125 spectroradiometer, Instrument Systems decided to equip the device with a CMOS sensor that is linked to a specially developed electronic readout circuit. This combination enables very low measurement times of 0.01 milliseconds while simultaneously optimizing long-term stability. The spectrograph design is based on the high-end CAS 140D device, which is already well established in the market. This gives the CAS 125 a level of optical performance comparable to that of the CAS 140D in terms of both stray light suppression and optical throughput. The device-specific electronic readout circuit enables time-optimized control of the spectrometer through parameterization of successive measurements in Recipe mode on the CAS 125. This eliminates the time-consuming step of communicating with the PC to initialize each subsequent stage of the measurement process.

Another unique feature of the CAS 125 sensor is its built-in temperature stabilization feature. This results in dark current behavior that is independent of the ambient conditions, enabling the CAS 125 to ensure optimum long-term stability even in environments where temperatures fluctuate. A further highlight is the ability to parameterize the flash trigger. This element helps users synchronize the spectrometer with other system components, for example by triggering a photodiode measurement. These key features – temperature stabilization and Recipe mode – are two of the CAS 125's unique selling points. They significantly improve automated processes in LED production, thus boosting productivity. ■

Vitrek's New Ultra High Accuracy Power Analyzer Sets New Standard for Price/Performance

Vitrek, the leader in high-voltage test and measurement equipment, introduces the PA920 Series Ultra High Accuracy Power Analyzer. The PA920 sets the new standard for accuracy (0.024% of reading) in the graphical power analyzer market. It integrates an ultra-high accuracy, wideband waveform digitizer with advanced computational capability, a large high-resolution display and a full-color touchscreen user interface.

The multi-channel PA920 offers unprecedented 0.024% power measurement accuracy for all channels (1–4 channel cards available per unit), innovative VPA architecture, 100 full precision readings per second and measurement bandwidths sufficient to handle 5 MHz signals – all at a cost far lower than less capable, competitive models. The unit's intuitive touchscreen operation – with built-in data history, scope mode and waveform zoom – allows users to explore many aspects of power measurement in greater detail than traditional power analyzers.

Vitrek's PA920 combines industry-leading power measurement accuracy (0.024%, 20 Hz–1 kHz), innovative multi-channel Virtual Power Analyzer (VPA) architecture; expansive harmonics analysis – also perfectly suitable for LED lighting applications

The PA920 delivers waveform visualization and measurement results necessary to validate the performance of power critical designs, such as LED lighting, solar power inverters, electric vehicles and aviation power distribution. Its Virtual Power Analyzer (VPA) functionality facilitates efficiency measurements, while its 0.024% basic accuracy and 5 MHz bandwidth provide world-class performance.

The PA920 includes the capability of measuring and displaying up to the 500th harmonic (even at aircraft frequencies) and multi-unit linking for complex efficiency and synchronous measurement applications. Integrated routines facilitate compliance testing to a selection a performance standard including: EN60034-2-1:2014 (motor drives); EN50564:2011 (standby power); EN61000-3-2 and 3-12 and 4-7 (harmonics emissions); RTCA DO-160E/F/G (avionics); Boeing 787B3-0147; Airbus ABD0100.1.8 (A380) and ABD0100.1.8.1 (A350) and more.

"The ultra-high accuracy levels of the new Vitrek PA920 power analyzers allow our customers to reach the highest standards of testing accuracy at a price that fits their budget," said Chad Clark, Vitrek's VP Sales and Marketing. "One of the reasons Vitrek continues to lead the industry on innovative testing equipment is because we strive to provide the highest level of features while keeping the price-point within the customer's equipment budget. Other industry leading power analyzers offering comparable features can cost more than twice the price of the PA920."

In addition to the PA920, Vitrek is also introducing the PA910 which offers accuracies of 0.045%power for applications where ultra-high accuracies are not required. Both the PA920 & PA910 are available as pre-configured or custom-configured units containing 1–4 channel cards. ■

Universal Lighting Technologies Expands EVERLINE® Retrofit Options for Commercial Applications

Universal Lighting Technologies, Inc., a global leader in lighting and a member of the Panasonic Group, recently introduced its EVERLINE® LRK34-ML LED Linear Retrofit Kits to its high-efficiency line of products, designed for commercial applications such as factories, warehouses and gymnasiums.

Universal Lighting Technologies' EVERLINE® LRK34-ML LED Linear Retrofit Kits are UL classified and efficiently replace T5HO and T8 light sources

The fast and easy-to-install LRK34-ML kit is intended for retrofitting mid and high bay T5HO and T8 fixtures. It comes with three EVERLINE LED light bars and a 0–10 V dimmable 80 W driver, providing 14,000 lumens. The LRK34-ML allows building owners and facility managers to replace the fluorescent system with a highly efficient LED light engine with no redesign or revised layout required. With an L85 lumen maintenance rating of greater than 60,000 hours, the LRK34-ML provides a brand-new light engine without having to replace the existing fixture housing.

"ULT is dedicated to providing cost effective solutions that save our customers time and money, allowing them to easily replace parts without a complete restructure," said Greg Bennorth, Product Director of LED for Universal. "Providing supreme flexibility for large scale commercial applications, the LRK34-ML aims to make retrofits easier than ever."

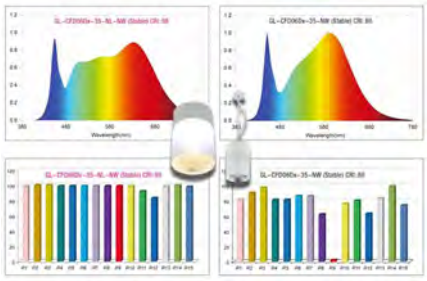
The LRK34 is UL classified and DesignLights Consortium® (DLC) Qualified. Designed for maximum durability, the LRK34-ML offers a seven-year warranty. It is available in 1-pack and 6-pack options. ■

HUMAN CENTRIC LIGHTING

GlacialLight – New Natural Sunlight of GL-CFD06Dx-35-NL Series with 3-in-1 and AC-TRIAC Dimming

GlacialLight, the LED lighting division of GlacialTech Inc., announces the natural sunlight GL-CFD06Dx-35-NL series. With a CRI of 98, as well as the CQS (Color Quality Scale) is up to 97. The color fidelity index (TM-30-15 Rf) and color gamut score (TM-30-15 Rg) are close to natural light. The GL-CFD06Dx-35-NL offers an optional decorative LED color ring, and a choice of surface or suspension mounting. It also features with 3-in-1 dimming and AC-TRIAC dimming functions for greater lighting flexibility.

The LED ring can shine through an optional red, green, blue, purple, or yellow color filter, to perfectly match your interior color scheme. The color ring illuminates independently. It won't visually conflict with the main light during operation. The standard product's default 3-in-1 dimming control adjusts both the main light and the sub light. The GL-CFD06Dx-35-NL is available with a choice of either surface or suspension mounting. It provides options to suit different design space.



GlacialLight's new natural sunlight version of the GL-CFD06Dx-35-NL Series is offered in two dimming versions: 3-in-1 dimming and AC-TRIAC dimming

The natural sunlight GL-CFD06Dx-35-NL series can improve the light experience for human health benefits. It closely matches the

spectrum of natural sunlight and harmonizes light output with natural circadian rhythms. The GL-CFD06Dx-35-NL is suitable for an extensive range of commercial and household applications to fit any attractive design environment. ■

CIRCADIAN ZircLight and Acuity Brands Announce Strategic Partnership

CIRCADIAN ZircLight Inc. announced a strategic partnership with Acuity Brands, Inc (NYSE:AYI) which will bring to the North American lighting market spectrally-engineered Zirc™ LED lights that boost human performance, health and well-being by entraining our natural circadian rhythms to mitigate the issues associated with circadian disruption.

"While the first generation of LED lighting radically improved energy efficiency, these LEDs were not designed to deliver the circadian light spectrum our brains and bodies require to entrain our circadian rhythms and promote health and well-being", explained Dr. Martin Moore-Ede, CEO of CIRCADIAN ZircLight, and former professor at Harvard Medical School. "This has had unintended consequences such as sleep disorders and fatigue and other health-related issues as acknowledged by the World Health Organization, American Medical Association and the NIH National Toxicology Program to be linked to the circadian disruption caused by the effects of continuous blue-rich lighting."

Evidence-Based Circadian Lighting

To develop LEDs that optimize human health and performance, CIRCADIAN ZircLight conducted multiple medical research studies to precisely define the circadian spectral characteristics of light under normal workplace conditions. At the University of Toronto Professor Robert Casper's team studied nurses and other volunteer subjects wearing eyewear spectral filters as they worked 12-hour night shifts. And Dr. Moore-Ede and his team at CIRCADIAN studied subjects working 12-hour day and night shifts under polychromatic white light sources with diverse spectral distributions and measured various physiological responses, including melatonin and insulin levels. This research discovered the circadian disruptive effects of light at night were largely confined to a narrow band of 440–490 nm blue light with a peak at 475 nm as defined by the Circadian Potency curve.

"People want healthy circadian lighting – demand is growing rapidly" said Dr. Moore-Ede. "But how do you determine if a light is truly a circadian solution? Our research revealed it's not by how warm or cold is the color temperature of the light, but rather by how much blue light is emitted between 440–490 nm. During the day, you want blue-rich light sources. But at night, you want as little blue light exposure as possible – ideally under 2%. Unfortunately, many circadian lights that are marketed for night use are well over this 2% threshold."

Spectrally Engineering the Optimal LED: 85-Fold Difference in Day and Night Blue Levels

Driven by the need to remove the harmful 440–490 nm blue wavelengths at night and restore them during the day, a bio-engineering team led by Dr. Moore-Ede spectrally engineered an innovative healthy white LED solution. CIRCADIAN® ZircLight's revolutionary Zirc™ technology – with Zirc™ Day LEDs and NightSafe™ LEDs – provides an unparalleled 85-fold day-night contrast between blue emission at the peak Circadian Potency 475 nm wavelength.

Compared to conventional LEDs with 15–20% blue emissions, the Zirc™ NightSafe™ LEDs deliver only 1% of 440–490 nm blue content, easily meeting the UL verification mark for lighting between sunset and sunrise of "Less than 2% Blue Light at Night." And during the day the Zirc™ Day LEDs deliver the rich blue content that is critical to entraining our circadian rhythms and promoting health and well-being.

Not only does Zirc™ patented technology provide a robust circadian entraining light solution, but with approximately 130 lumens/watt delivered 24/7 the Zirc™ LED technology delivers energy-efficiency without sacrificing health benefits.

"As a market leader in lighting and building management solutions, we are very excited to be working with CIRCADIAN to commercialize circadian lighting technology to support our customers' growing desire to use lighting that is designed to promote well-being," said Rick Earlywine, Acuity Brands Lighting Senior Vice President, Architectural Lighting Solutions.

Why 475 nm Blue Light is the Peak Circadian Signal

Billions of years ago when life first began, the only part of the sunlight spectrum that penetrated the ocean depths was 475 nm blue. All other spectral colors in sunlight are absorbed by sea water, so days were blue and nights black. Circadian clocks evolved using 475 nm blue as the signal for day and night. New research now shows that our eyes, like the primitive ocean life, use blue light with a peak wavelength of 475 nm as the signal for circadian entrainment. While short exposures in dark adapted laboratory volunteers may show some transient effects of violet and green, the key circadian signal is 475 nm blue. Circadian ZircLight™ LED's are spectrally engineered to adhere to this fundamental law of nature.

In the natural world there is a greater than five orders of magnitude day-night contrast in 475 nm blue between a 10,000 lux cloudy day and 0.1 lux of full moonlight which provides a strong circadian entrainment signal. But unlike our ancestors we spend over 93% of our time indoors with conventional fluorescent and LED lighting which can emit too little blue rich light during the day and too much blue-rich light at night.

"Our goal was to create lights that combine the longevity and energy efficiency of LEDs with the ideal spectrum of light by time of day, season and geographical location to entrain circadian rhythms and optimize human health and performance", explained Dr. Moore-Ede. "Our NightSafe™ LEDs utilize a violet pump to provide the same white color and alertness promoting effects offered by traditional blue-pump LEDs without the effects of blue at night. These lights boost alertness and productivity while eliminating the circadian disruption caused by the high nocturnal sensitivity of circadian rhythms to 440–490 nm blue light after sunset."

Alertness and Productivity at Night Safely Delivered

Light is energizing especially when it contains shorter wavelengths such as blue and violet. Some have suggested using blue rich light at night to prevent fatigue, but that produces circadian disruption and health risks. Zirc™ Night LEDs elegantly solve this problem by providing safe violet content, which is even more effective than blue at promoting alertness and productivity without disrupting our circadian clocks.

Evening or night-shift workers no longer need to dim the lights, or use low visual acuity orange-yellow lighting, to avoid the effects of blue-rich light at night. Spectrally engineered Zirc™ Day and Night light engines provide attractive energy efficient circadian healthy white light 24/7. As an added bonus the Zirc™ technology is ideal for 24/7 clinical observations of skin color with the Zirc™ Night 1.8 and Zirc™ Day 2.2 indices easily meeting the COI (Cyanosis Observation Index) requirement of <3.3. ■

SMART & IOT

Cree Lighting Improves Outdoor and Industrial Intelligent Lighting

Cree Lighting announced the availability of Synapse®SimplySNAP intelligent lighting controls for the OSQ Series area, IG Series parking structure and KBL Series high-bay luminaires. These Cree Lighting luminaires overcome the challenges of outdoor and industrial environments to provide maximum

CREE® J SERIES® 5050 LEDs: New P Class Versions Deliver Industry-Leading Efficacy at 1W

The J Series 5050 LEDs combine high efficacy (up to 211 LPW) and excellent value in a reliable package and are optimized for medium density lighting applications where extended lifetimes are required, such as street lights, outdoor area and indoor directional lights. Available in 2700K - 6500K with high CRI and 6V, 9V, 12V, 24V & 36V selections in an industry-compatible size of 5.0 mm x 5.0 mm.

www.cree.com/led-components/products/j5050/jseries-5050?WT.mc_id=CRX1940

energy savings, responsive illumination and a better user experience.

"More and more customers are looking for intuitive, intelligent lighting solutions," said Tom Hinds, director, intelligent lighting, Cree Lighting. "Cree Lighting's area, parking and high-bay luminaires enabled with SimplySNAP deliver just that for outdoor and industrial applications and are a great complement to Cree Lighting's SmartCast Intelligence Platform™ for indoor applications including office, education, and healthcare."

Controlling traditional outdoor and industrial fixtures using fluorescent, high-pressure sodium and metal halide lighting has historically been a challenge. Control schemes for these traditional lighting solutions are very complex, expensive, inefficient, and often result in shortened lamp life or just aren't practical. Furthermore, many control schemes are installed in the field without any testing for interoperability between drivers and components or wireless performance.

Cree Lighting improves outdoor and industrial intelligent lighting

Intelligently enabled Cree Lighting LED luminaires solves all those problems. The system uses a reliable, secure, and robust wireless mesh network that has been extensively vetted and rigorously tested for interoperability and performance. It is truly scalable with the ability to integrate with a variety of third-party building management systems (BMS) and platforms. In the end, customers have the confidence of an extensively tested, single-source solution that empowers end users to commission, maintain and adjust the system themselves.

Specifying, installing, using and securing outdoor or industrial lighting controls is now a snap. The intelligent lighting solution provides simple stand-alone functionality right out of the box and can be setup on-site or remotely. The user interface is simple to navigate, mobile-friendly and browser-based.

Meanwhile, an internet connection, costly integration or third-party hardware or software are not required.

Once the system is set up, users have the flexibility to control light levels, utilize motion and ambient light sensors, and set event triggers via programmable schedules for both individual luminaires and designated zones. The entire lighting network can also be managed and reconfigured with ease.

Users can manage the system through a web-based user interface via Ethernet or wireless connection to a PC, tablet or smartphone to access data on power, zones, triggers and alarms, and critical events for analytics, maintenance and troubleshooting. A 2.4 GHz Wi-Fi mesh network connects up to 1,000 luminaires to a site controller up to a mile away and is future ready, scalable and integratable. All wrapped in a secure, commercial-grade industry-standard AES 128-bit encrypted network giving users the protection they demand in an era of heightened cyber security.

"Cree Lighting luminaires enabled with SimplySNAP are a secure end-to-end system that is simple to install, easily customized, and comes with stand-alone functionality that scales to campus-wide deployments," concluded Hinds. ■

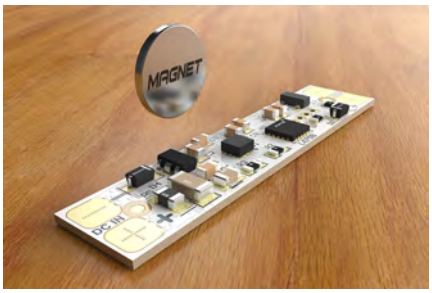
Cezos Introduced New Magnet Switch for Inside Cabinet LED Lighting

Cezos is delighted to present their new magnet switch, L475T, which is a specialized controller designed to drive a LED light inside cabinets etc. Due to a 3-axes MEMS magnetometer sensor it can detect minimal changes precisely in the magnetic field. Therefore, the distance to the magnet can be wider than with traditional sensors (e.g. mechanical). The calibration algorithm detects the best axis when the door is opened for the first time, so the mounting direction is not relevant. The soft adjustment of the light protects the eyes. If the door is not closed, the light turns off automatically after 15 minutes.

Features:

- Input voltage: 8–27 V DC
- Maximum output current: 3 A
- Dimensions: 35×8×2 mm
- The controller is designed for DC LED strips and DC LED modules

The ultra-low-power high-performance three-axis magnetic sensor is a key component of the controller. The choice of this component was determined by its high measurement speed, 16-bit resolution, and small size.



Cezos' new magnet switch, L475T, with its ultra-low-power high-performance three-axis magnetic sensor offers many useful features for its applications like inside cabinet LED lighting

The controller continuously registers the magnetic field values and in the event of its rapid rise or fall, switches the light source on or off. To achieve high measurement precision, it works on the lowest measuring range ±4 gausses. Thanks to advanced analysis of the rate of increase and decrease of the magnetic field, the sensor can function properly at a distance of 300 mm from a small cylindrical neodymium magnet with a diameter of 30 mm and a thickness of just 2 mm. With larger magnets, it is possible to work at a distance of one meter, but in most furniture installation applications, the mounting distance is 50–200 mm. For such applications, a small 20×20×1 mm small neodymium magnet will suffice. The magnet can also be inserted into the furniture board, and thus it will be completely invisible.

Large and strong neodymium magnets should not be used in the case of a short distance from the controller <50 mm, because there is a risk of exceeding the measuring range and incorrect operation of the controller. The calibration algorithm detects the best axis

when the door is closed for the first time, so the installation direction of the controller is irrelevant. Data collected during the first calibration are automatically saved in the controller's memory. This recording remains in memory even after the power is turned off, and there is no need for re-calibration. The controller has a soft start function. If the door is open for more than 15 minutes, the lighting will be turned off automatically.

Against the background of alternative solutions used in the furniture industry, the controller containing a magnetometer is distinguished by great freedom of location and the possibility of completely concealing. The magnet necessary for this solution can be easily attached to the inside of the door using double-sided tape or completely hidden inside the furniture board. ■

Inventronics Expands Next Gen Platform: More Compact, Global IP66/IP67 LED Drivers

Inventronics has expanded their new family of programmable, IP66/IP67 LED drivers to include model offerings that cover 75 W and 100 W power levels. These new models are an extension to their existing 150 W, 200 W and 240 W series.

Equipped with similar features like their recently introduced relatives, Inventronics' new EUM-075SxxxDG and EUM-100SxxxDG offer durability, compact design and IP66/IP67 protection

The EUM-075SxxxDG and EUM-100SxxxDG series provide the same next generation platform offering an optimized design utilizing new features to help reduce SKUs, offer even more design flexibility and a simplified way to conduct hi-pot testing. The new platform is equipped with an enhanced transformer design, optimized components that provide lower costs without sacrificing quality or performance and a new thermal design methodology to support a warranty Tc of 80ºC.

The EUM-075SxxxDG series currently offers 3 constant-power, programmable models delivering 75 W at output currents from 700 mA to 2100 mA with a calculated lifetime up to 100,000 hours. The EUM-100SxxxDG series currently offers 3 constant-power, programmable models delivering up to 100 W at output currents from 700–2800 mA with a calculated lifetime up to 114,000 hours. Each series provides a multi-layer of protection which includes over-voltage, over-temperature, and short-circuit protection.

They offer a high level of flexibility with an ultra-compact design that is smaller than previous generation Inventronics drivers, allowing them to fit inside a multitude of luminaires. Their programmable interface and constant-power operation allow for optimization to achieve ideal results and various current configurations without the need of powering on the driver. They are also equipped with a global cable that is suitable to be used world-wide which provides OEMS with reduced inventory SKUs and carrying costs associated with overstocking products. The new series are approved to UL, FCC, ENEC, CE, CB, CCC, PSE, KS, KCC, BIS, EAC and Independent Use certifications.

The EUM-075SxxxDG and EUM-100SxxxDG also offer improved safety with a wide range of isolated dimming options to remain compliant with all standards including the new UL May 2020 requirements, as well as supporting Class 1 and Class 2 wiring. The dimming controls include isolated 1–5 V, 1–10 V, PWM and multiple timers.

Utilizing the new proprietary circuit, they are still able to maintain an industry-leading surge protection of 6 kV (differential mode) and 10 kV (common mode) while passing typical hi-pot testing for luminaires without any secondary operation. The rugged, extruded-metal housing, which utilizes an exclusive encapsulation process, is IP66 and IP67 rated and specially designed to operate in harsh conditions and demanding applications such as high bay, high mast and roadway lighting. ■

Espen Technology Adds 10 W, Type B, Emergency Driver to Extensive EM Solution Line

Espen Technology announced the release of its new 10 W Type B Emergency Driver, adding to its already extensive line of emergency solutions for LED linear retrofits. The new model No. VEMB10W emergency driver provides 90 minutes of emergency operation during a power outage, ensuring building occupants can safely get out of the building.

This model is specifically for Type B LED tubes, which operate directly using line voltage, 120–277 VAC input. The emergency driver utilizes advanced lithium-ion batteries, and are UL 924 safety listed, for loads up to 10 W.

With its 90 minutes of emergency operation time and UL 924 safety listing, Espen's new Type B emergency driver is a clever choice

According to John Clancy, SVP of Sales & Marketing at Espen, "Espen Technology offers one of the largest lines of emergency LED drivers for Types A, B, and C TLEDs." Clancy added, "We've become the leading supplier of emergency solutions for LED linear retrofits." ■

LSI Industries Launches Enhanced, Multi-Setting, Edge-Lit LED Panel

LSI Industries said that the company has launched an enhanced version of its edge-lit LED panel. The new luminaire features an innovative upgrade that enhances its versatility across numerous indoor applications, including schools, offices, hospitals and stores.

"Our enhanced, edge-lit LED panels fill a void in the marketplace," said Mike Prachar, Chief Marketing Officer of LSI Industries. "They give customers significant flexibility to customize and optimize the use of light in different areas throughout their facilities."

LSI Industries' enhanced version of its edge-lit LED panel features a power settings option (inset)

LSI's enhanced, edge-lit flat panel differentiates itself in the marketplace in a novel way. While similar lights allow customers to adjust color temperature or wattage, LSI's product gives them the ability to adjust both. In addition, customers can select up to three different options for both color temperature and wattage, giving them a total of nine different light settings from a single fixture.

This gives facility managers, and others responsible for the property, significant flexibility to customize and enhance employee workspaces, increase safety and conserve energy.

Edge-lit panels, such as LSI's enhanced LED product, differ from other light sources in that they produce light from the sides, not the back. This makes them extremely thin and lightweight, which allows them to be mounted in a variety of applications. LSI's edge-lit LED panels are easy to install and available in multiple sizes, including 1×4, 2×2 and 2×4 feet. ■

Douglas Lighting Controls® Introduces the Conference Room Controls App to its Bluetooth® Wireless System of Devices

Douglas Lighting Controls®, a member of the Panasonic family of companies, recently announced the pairing of its Conference Room Controls App to its system of Bluetooth® Wireless devices. Designed for conference room and boardroom applications, the new iPad control console pairs seamlessly with Douglas Lighting Controls' Bluetooth Wireless eco-system of devices to provide a modern, large format touch screen interface for control functionality.

Douglas Lighting Controls' new control console with the Conference Room controls app pairs seamlessly with the company's Bluetooth® wireless system of devices

The Conference Room Control App has the ability to support up to eight zones with a maximum of eight presets. It provides customers with a simple, touch screen solution for controlling light in conference room atmospheres. The app allows users to create preset scenes like meeting, presentation, and video to quickly set the desired light levels with one tap on the screen.

"Modern boardrooms want to showcase the latest technology as this is where their senior executives and best customers will meet," said Audey Korpus, Senior Product Manager at Douglas Lighting Controls. "A user-friendly interface featuring Bluetooth wireless technology for controlling the lights is a great way to enhance a modern boardroom and present a technology forward experience."

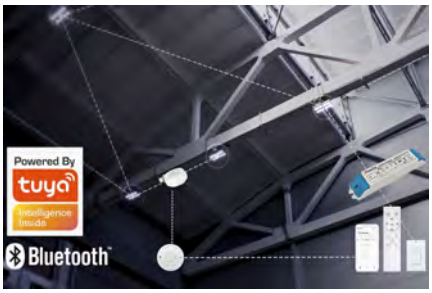
The control console app operates on an Apple iPad to set and adjust lights that are controlled with the Bluetooth Wireless ecosystem. Featuring mounting hardware for wall or tabletop applications, the app offers a solution designed to meets specific room requirements for any user. The wall mount can be used in place of wall station switches or a table mounted control solution can be used to place controls directly on the boardroom table or a convenient side table.

The Douglas Conference Room App is available to download free on the Apple App Store: Search for Douglas Lighting Controls BTCR. ■

Upowertek Launched 30 W Tunable White LED Driver

Upowertek launched a new product – 30 W tunable white LED driver BPR series. It has two channel output, which controls the warm and cold LED modules separately, users could adjust the color temperature and intensity by cellphone, remote controller and wall switch.

Tunable white LED lighting adjusts color temperature to produce a suitable environment for human beings according to different times or locations. There are numerous reasons why tunable white lighting might be preferred for an architectural space. Tunable White lighting is lighting that can dynamically change CCT through controls. This enables the creation of scenes and modes that can be aligned with key activities or follow the rhythm of the day.



Upowertek's new 30 W tunable white LED driver can be fully controlled in a Bluetooth environment

Built-in with wireless control modules like Tuya Pro BLE module, BPR-030 series supports Bluetooth Mesh, and all the LED lights can be controlled individually or in group. ■

Xicato Expands Family of Miniature Smart Drivers with Wireless Control

Xicato, the leading provider of smart building wireless controls and highest quality light sources, announced the general availability of XMD, a purpose-built form factor Xicato grade driver that fits into compact track adapters for elegant designs. XMD's narrow, rectangular and low-profile footprint allows Luminaire designs with minimal visual impact with deep-dimming and smart driver control with wireless BLE option.

Key features and benefits:

- XMD measures 12.5×77×6 mm (about the size of a stick of chewing gum) while XID comes in disk form factor at ø48×12 mm
- Both drivers accept a 48 VDC input and power luminaires at up to 60 W while supporting deep, flicker-free dimming to 0.1%
- Both drivers have a programmable constant current output from 175 mA to 1400 mA and 2.5 V to 45 V
- XID supports 0–10 V input control while XMD supports a 100 kΩ POT for trim control
- The Optional meshed Bluetooth control

available for both drivers, can be over-the-air (OTA) updated, and is able to be migrated to standard Bluetooth mesh

XMD joins the widely regarded XID, which comes in disk form factor and has been used in downlight, spot, and cylindrical pendant applications. Both provide the deepest flicker-free dimming to 0.1% that Xicato drivers are renowned for, achieving a level of natural control that leading architects and designers strive for and can be optionally paired with Bluetooth wireless mesh for intelligent, individual, wireless lighting fixture control further expanding the driver options for our customers.

XMD is already entering the market alongside A.A.G. Stucchi, where its tiny printed circuit board assembly fits completely inside the Stucchi DC track adapter; "Flicker free dimming is crucial in delivering the most elegant lighting experiences. XMD does just that while fitting discretely within adapters for our low voltage MULTISYSTEM® tracks," Aristide Stucchi, President of A.A.G Stucchi.

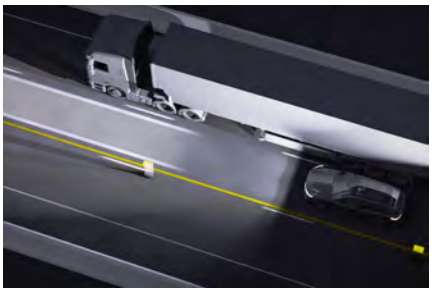
Xicato's new XMD smart driver enables 0.1% flicker-free dimming of track and linear fixtures

"With XMD, we are providing an option toward Xicato's goal of enhancing spaces while supporting the light designer's need for solutions that virtually disappear", said Amir Zoufonoun, Xicato's CEO. "Our best in class lights will be supported by an expanding portfolio of best in class drivers that meet Xicato's standards of quality to provide complete solutions". ■

AUTOMOTIVE

Hella Announces Development of High-Resolution Lighting System Digital Light SSL|HD

With the new high-resolution lighting system "Digital Light SSL|HD", the lighting and electronics expert HELLA is making a further significant contribution to greater safety and comfort in road traffic. With this lighting technology, more than 30,000 pixels can be controlled intelligently and individually, thus bringing about numerous new safety functions like optical lane markings. Furthermore, original equipment manufacturers and end customers can use SSL|HD technology to implement and experience further options allowing enhanced individualisation, such as coming and leaving home animations as well as communication functions.



Over 30,000 pixels of Hella's Digital Light SSL|HD system increase safety and comfort on the road

"Automotive lighting technology continues to gain in importance. We are setting a new milestone in this direction and bringing the next generation of headlamps onto the market with our digital SSL|HD light," explains Dr. Frank Huber, member of the HELLA management board and responsible for the global lighting business. "The focus of this latest innovation for us is always the direct customer benefit. With these new lighting functionalities, we want to create an optimal view of the road, increase the safety factor in road traffic and further enhance comfort for drivers and passengers alike."

Lighting system implements new safety-enhancing functions

The SSL|HD lighting technology not only further improves established lighting functions such as adaptive, glare-free high beam, it also enables additional light-based safety functions, for instance in the form of an optical lane assistant. This can, for example, indicate the optimum lane to take when driving past road works and thus provide the driver with additional support in order to achieve safe and stable vehicle guidance. Another possible safety-enhancing functionality is the projection of protection areas for cyclists or pedestrians.

The "Digital Light SSL|HD" also makes it possible to open up perspectives for new business models. Against this backdrop, HELLA offers original equipment manufacturers the option of freely programming lighting functions or developing new business models on a pay-per-use basis. Certain lighting functionalities are always stored in the vehicle, but are only activated on request in line with individual user requirements, and can for example be controlled and paid for via a mobile device.

"Digital Light SSL|HD" to go into series production in 2022

"Digital Light SSL|HD" is a consistent further development and miniaturisation of existing matrix LED systems. Together with an enlarged light-emitting surface, the significantly higher number of pixels in particular is the basis for a multitude of new functionalities. The more than 30,000 light points are generated by light sources just the size of a fingernail. The SSL|HD technology therefore requires less installation space but nevertheless provides greater efficiency while also giving vehicle manufacturers more freedom in their individual design of vehicles. A first customer order from a European premium manufacturer for large-scale production has already been acquired. Series production will commence in 2022. ■

RESEARCH

Research Confirms that Light Pollution Can Suppress Melatonin Production in Humans and Animals

Melatonin sets the internal clock. Researchers from IGB in an international team have analyzed data on the impact of light pollution on melatonin formation in humans and vertebrates. They found that even the low light intensities of urban skyglow can suppress melatonin production. Melatonin influences the metabolism and other body functions.

Melatonin synchronizes the day-night-rhythm in animals and humans. It adjusts the circadian clocks of cells, tissues and organs, and regulates other seasonal processes like reproduction. In vertebrates, differences in light levels are detected by photoreceptors for example in the retina. At high light levels, melatonin production is suppressed. In darkness, melatonin is produced.

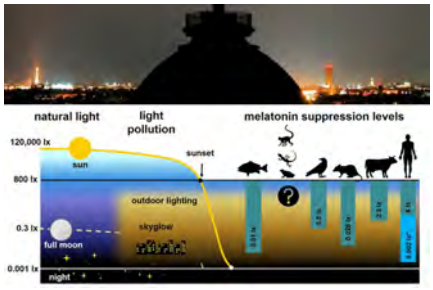
The sensitivity threshold for humans is 6 lux – street lighting is typically higher

Artificial light at night can disturb the nocturnal melatonin production. Within a literature review of 1900 studies, the researchers identified 72 relevant works that fulfilled their criteria for light pollution. Based on the data, they showed that even very low illuminance levels can suppress melatonin production for some vertebrate classes: in fish the threshold is 0.01 lux, in rodents 0.03 lux and in sensitive humans 6 lux; pure blue light showed much lower thresholds.

For comparison, the illuminance levels at night: on a starry night, the illuminance is 0.001 lux. On a full-moon night it reaches a maximum of 0.3 lux. The skyglow of a city, a form of light pollution, can reach illuminances

of up to 0.1 lux, and outdoor lighting on the order of 150 lux.

"Surprisingly, the low light levels of skyglow are sufficient to suppress melatonin production in several vertebrate classes", says first author Dr. Maja Grubisic from IGB Berlin. "Skyglow affects large areas on a world-wide scale, as we know from satellite data", adds her colleague Dr. Andreas Jechow. The light from artificial lighting shines into the night sky, brighter with rain and snow, and is reflected by clouds and particles, which is called skyglow. The scientists unraveled several knowledge gaps: "There are no studies on melatonin and light pollution in reptiles and amphibians and no long term-studies at all. Particularly, the impacts on human health are not fully understood", says IGB researcher Dr. Franz Hölker, head of the study.



The sky above Berlin – is not dark at night (top | photo credits: Chris Kyba). Illuminance levels in the course of a day and melatonin suppression levels of different species

Read the study Open Access in the journal Sustainability:

Grubisic, M.; Haim, A.; Bhusal, P.; Dominoni, D.M.; Gabriel, K.M.A.; Jechow, A.; Kupprat, F.; Lerner, A.; Marchant, P.; Riley, W.; Stebelova, K.; van Grunsven, R.H.A.; Zeman, M.; Zubidat, A.E.; Hölker, F. (2019) Light Pollution, Circadian Photoreception, and Melatonin in Vertebrates. Sustainability, 11, 6400. DOI: https://doi.org/10.3390/su11226400 ■

Tailored Light Improves Sleep Quality, Depression, Agitation in Older Adults with Alzheimer's Disease

Most people associate Alzheimer's disease with profound memory loss, but it is often the symptoms – sleep disturbances, depression, and agitation – that are a challenge to treat, and can significantly reduce the quality of life for both the affected individual and their family members and caregivers. In a research project funded by the National Institute on Aging (NIA), Dr. Mariana Figueiro, Professor and Director at the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute, is investigating whether a tailored lighting intervention can lessen the impact of these symptoms in older adults living with Alzheimer's disease and related dementias (ADRD).

Summary of the findings that have been published in the Journal of Clinical Sleep Medicine:

Using a variety of light sources such as floor luminaires, light boxes, and light tables to deliver the tailored, individualized lighting intervention, this 14-week randomized, placebo-controlled, crossover design clinical trial administered an all-day active (high circadian stimulus [CS] of 0.4) or control (low CS of < 0.1) lighting intervention to 46 patients with moderate to late-stage ADRD in eight long-term care facilities. The study employed wrist-worn actigraphy and standardized measures of sleep quality, mood, and behavior.

The study's primary aims were to extend earlier studies and to again validate the CS metric in the field by investigating the impact of the intervention on subjective and objective measures of nighttime sleep. The secondary aim was to determine whether the lighting intervention would improve caregiver-assessed participant scores in measures of depression, agitation, and quality of life. The CS metric is a measure of how effective a light exposure is for stimulating the human circadian system. Developed by the LRC from several lines of biophysical research, including those from basic retinal neurophysiology, the CS metric has been applied successfully in numerous field applications to improve sleep at night and reduce sleepiness during the day. Results revealed that, compared to baseline, the active lighting intervention significantly improved sleep quality, and reduced depressive symptoms and agitation behavior.

The 24-hour light and dark pattern strongly determines a person's sleep–wake (circadian) cycle, telling the body when to go to sleep and when to wake up. Studies have demonstrated that daytime light exposure of CS > 0.3 (approx. 350–500 lux at the eyes) can improve nighttime sleep efficiency and increase daytime wakefulness by promoting circadian entrainment.

Lighting in long-term care facilities is usually not bright enough during the day and perhaps too bright during the evening. Typical indoor lighting provides less than 100 lux at the eye, whereas being outside on a sunny day will provide anywhere from 1,000 to more than 10,000 lux at the eye. Older adults in long-term care facilities often spend their days and nights in dimly-lit rooms with minimal time spent outdoors, and thus, are not experiencing the robust daily patterns of light and dark that synchronize the body's circadian clock to local sunrise and sunset.

Therefore, it is understandable that many older adults in long-term care facilities are plagued by insomnia and other sleep disorders – yet, sleep could not be more important to their overall health and wellbeing. Recent research has shown that poor sleep may directly impact the onset and progression of Alzheimer's disease, and conversely, healthy, regular sleep patterns may prevent or slow progression of the disease. This research suggests a bidirectional relationship between sleep disruption and the deposit of amyloid beta, the main component of the amyloid plaques found in the brains of individuals diagnosed with Alzheimer's disease.

Older adults with ADRD experience severe dysfunctions of their sleep–wake cycle that clinically present as sundowning, excessive daytime sleepiness, nocturnal wandering, agitation, irritability, day–night reversal, and decreased cognitive functioning. Sleep problems are exacerbated in those with ADRD, whose circadian rhythms can become less consolidated, as manifested in increased nocturnal wandering. This population is also at higher risk for depression and agitation behavior. These disturbances can lead to their placement in long-term care facilities, where they experience even greater inactivity and reduced exposure to daytime circadian-effective light, exacerbating their symptoms further.

Dr. Mariana Figueiro behind one of the light tables that was used in the study

Dr. Figueiro began work on her first major research grant from the NIA in 2010, measuring circadian light exposures in individuals with ADRD. Her research revealed that individuals with ADRD were exposed to lower light levels, exhibited lower activity levels, and experienced greater circadian disruption than healthy older adults. She then focused on a specific challenge: delivering light in a way that was highly effective for individuals with ADRD. A successful example of this tailored, personalized lighting intervention is the light table, which can deliver a strong dose of light at the eyes, an important factor in stimulating the circadian system. Light has to enter the eye to be effective for circadian entrainment. Although a Cochrane review published in 2014 casts doubt on the efficacy of light therapy for improving sleep and behavior in ADRD patients, if carefully specified and implemented, tailored lighting designed to maximally impact the circadian

system can be a powerful non-pharmacological intervention for improving sleep, mood, and behavior in persons living with ADRD, as shown in this study and in previous studies.

"When delivered appropriately, using CS and different delivery modes, and accurately measured, using calibrated personal light meter devices, a lighting intervention tailored to maximally entrain the circadian system will significantly improve sleep quality, depressive symptoms, and agitation behavior in patients with ADRD," said Dr. Figueiro. "It is important to use, deliver and measure the right lighting to see the positive effects." "We are hopeful that designers of senior facilities will now have the confidence to specify lighting solutions that provide a minimum CS of 0.3 during the day to this often neglected population," said Dr. Mark Rea, who was one of the authors of the study. For more detailed information, please read the full journal article published in the Journal of Clinical Sleep Medicine at http://jcsm.aasm.org/ViewAbstract.aspx?pid=31734

Future Research

Last year, the NIA awarded a 5-year grant to Dr. Figueiro to continue her research. Figueiro will serve as Principal Investigator and will work with researchers at the Icahn School of Medicine at Mount Sinai to study whether a tailored lighting intervention designed to promote circadian entrainment can reduce metabolic impairment in people living with Alzheimer's disease. Under a separate NIA grant awarded earlier this year, Dr. Figueiro is also investigating whether a long-term (6-month) lighting intervention designed to promote circadian entrainment will improve sleep, cognition, and memory in individuals with mild cognitive impairment (MCI), which is an "at risk" or potential prodromal stage of dementia. Sleep–wake disturbances are evident in approximately 60% of individuals with MCI. Healthy sleep could improve both working and long-term memory, and in a best-case scenario, prevent onset of Alzheimer's disease. ■

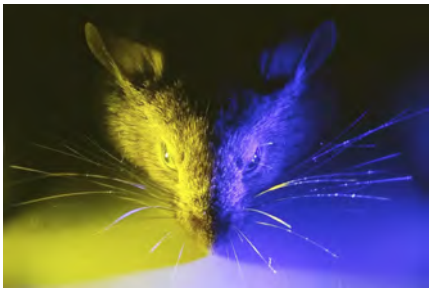
University of Manchester Scientists Suggest Blue Light Not So Disruptive to Sleep as Thought

Contrary to common belief, blue light may not be as disruptive to our sleep patterns as originally thought. According to the team, using dim, cooler, lights in the evening and bright warmer lights in the day may be more beneficial to our health. Twilight is both dimmer and bluer than daylight, they say, and the body clock uses both of those features to determine the appropriate times to be asleep and awake.

Current technologies designed to limit our evening exposure to blue light, for example by changing the screen color on mobile devices, may therefore send us mixed messages, they argue. This is because the small changes in brightness they produce are accompanied by colors that more resemble day. The research, which was carried out on mice, used specially designed lighting that allowed the team to adjust color without changing brightness. That showed blue colors produced weaker effects on the mouse body clock than equally bright yellow colors. The findings, say the team, have important implications for the design of lighting and visual displays intended to ensure healthy patterns of sleep and alertness.

The study is published in Current Biology and funded by the Biotechnology and Biological Sciences Research Council. The body clock uses a specialized light sensitive protein in the eye to measure brightness, called melanopsin, which is better at detecting shorter wavelength photons. "We show the common view that blue light has the strongest effect on the clock is misguided; in fact, the blue colors that are associated with twilight have a weaker effect than white or yellow light of equivalent brightness" says Dr Tim Brown. This is why, say the team, researchers originally suggested blue light might have a stronger effect.

However, our perception of color comes from the retinal cone cells and the new research shows that the blue color signals they supply reduce the impact on light on the clock. Dr Tim Brown, from The University of Manchester, said: "We show the common view that blue light has the strongest effect on the clock is misguided; in fact, the blue colors that are associated with twilight have a weaker effect than white or yellow light of equivalent brightness. There is lots of interest in altering the impact of light on the clock by adjusting the brightness signals detected by melanopsin but current approaches usually do this by changing the ratio of short and long wavelength light; this provides a small difference in brightness at the expense of perceptible changes in color."



Research results from the University of Manchester on mice suggest that dim, cooler, lights in the evening and bright warmer lights in the day may be more beneficial than the currently propagated approach

He added: "We argue that this is not the best approach, since the changes in color may oppose any benefits obtained from reducing the brightness signals detected by melanopsin. Our findings suggest that using dim, cooler, lights in the evening and bright warmer lights in the day may be more beneficial. Research has already provided evidence that aligning our body clocks with our social and work schedules can be good for our health. Using color appropriately could be a way to help us better achieve that."

The paper Cones support alignment to an inconsistent world by suppressing mouse circadian responses to the blue colors associated with twilight is published in Current Biology.

Acknowledgements: The study is published in Current Biology and funded by the Biotechnology and Biological Sciences Research Council.

Reference: News release from The University of Manchester – December 16th, 2019: https://www.manchester.ac.uk/discover/news/researchers-discover-when-its-good-to-get-the-blues/ ■

TECHNICAL REGULATORY COMPLIANCE UPDATE

Segment	Product	Standard (Certification)	Region	Technical Regulatory Compliance Information
Energy Efficiency	Energy efficiency labeling of LED lamps	Resolution No. 795/2019	Argentina	On 29 November 2019, Resolution No. 796/2019 of the Ministry of Production and Work Secretary of Internal Trade was adopted regarding the labelling and certification of LED lamps and is in force (since Dec 03, 2019). The purpose of this resolution is to define requirements and essential characteristics for energy efficiency labelling that must be met by LED lamps for general lighting . National manufacturers and importers have to ensure the compliance with the requirements and the conformity assessment procedure established in the Annex. Excluded from the scope of this resolution are: • LED lamps whose luminous flux is less than 30 lm; • LED lamps operating with batteries; • LED lamps that incorporate the possibility of colour change; • LED lamps with colour diodes and/or with colour coating; and • LED lamps that do no connect directly to the power supply network. In Section 3.1 the details of the labelling requirements are set. Products covered by this measure must carry the energy efficiency label on the product packaging and provide information on the nominal life of the lamp in accordance with IRAM 62404-3. To ensure compliance with these requirements, manufacturers and importers require clearance prior to the release of products on the market. To obtain such clearance, manufacturers and importers must submit the documentation specified in section 5.1 of the Annex to the Commercial Loyalty Department through the remote procedures platform (TAD). Clearance will subsequently be approved through the issuance of a product certificate. This Resolution entered into effect upon publication on 3 December 2019.
Energy Efficiency	Labeling and certification of household appliances	Resolution No. 86, 2015	Uzbekistan	The Resolution No. 860/2019 amends the Resolution 86/2015 and affects the mandatory energy labelling and certification of household Appliances. In this amendment the scope of the requirements is extended by making several additions to adjoining Annex of Resolution No. 86/2015. In particular, it extends the requirements of mandatory labelling and technical documentation to the following: 1. Central heating boilers, 2. Electric hoods with a horizontal size of not more than 120cm, 3. Vacuum cleaners, 4. Electromechanical household machines with a built-in electric motor, 5. Light emitting diodes (LED), 6. Lamps and lighting equipment, and 7. Other appliances intended for use with incandescent lamps. It came into force on 11 October 2019.
Energy efficiency	Lighting products and separate control gears	(EU) 2019/2015 + (EU) 2019/2020	Europe	On 5th of December the EU published the first version of the so called – single lighting regulation – which covers lightsources of all kind of technologies and separate control gears. In this regulation the energy performance criteria as well as the energy labeling of lighting products is described and will come into force in September 2021. The energy classes in this regulation will go from A to G and also test parameters regarding endurance and such are adapted to all technologies. There are now 2 new regulations published on this topic: The single lighting regulation which defines overall eco design requirements for lightsources (EU) 2019/2020 and the new energy label for lightsources (EU) 2019/2015 which replaces the old (EU) 874/2012 and (EU) 2017/1369. From 25th of December the energy label for luminaires is no longer valid and therefore should no longer be displayed on products and packaging.

Limits for Flicker and Stroboscopic Effects

On December 5th, 2019 the EU published commission regulation (EU) 2019/2020 “Ecodesign Requirements for Light Sources and Separate Control Gears”. As its predecessors 244/2009, 245/2009 and 1194/2012 it focuses not only on energy savings but also on light quality. These two aspects are contradictory in many cases and manufacturers must find compromises for the good of the customers.

While 244/2009 defined light quality consisting mainly of life time, color, color rendering, luminance and UV radiation, the new regulation also adds aspects of time dependent behavior like flicker and stroboscopic effects. As there is an ongoing discussion on this matter, especially concerning the limits for these effects, LED professional wants to discuss two of the most cited papers of last year on this topic.

Flicker and Stroboscopic Effects

A temporal light artefact (TLA) is an effect perceived by humans that arises as a result of temporal modulation of the light output of a light source. Temporal modulation may or may not generate TLA, depending on the characteristics of the modulation waveform. The two most well-known TLAs are flicker and stroboscopic effect. Both may or may not have psychological (e.g. acceptance, concentration) and physiological (e.g. eye strain, headache) impacts on humans.

Flicker is the perception of visual unsteadiness induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a static observer in a static environment. Flicker is perceived at low modulation frequencies below 80 Hz. Incontrary, the stroboscopic effect is a change in motion perception by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a static observer in a non-static environment. Stroboscopic effect may be perceived at frequencies higher than 80 Hz [1].

Visibility for both effects can be observed in experimental setups and can be correlated to modulation parameters as modulation depth, frequency and waveform. There are two metrics that may be calculated from modulation parameters and can be used to characterize visibility of the effects:

- Short term flicker severity (Pst^{LM}): $Pst^{LM} = 1$ means that the observer detects flicker with a probability of 0.5
- Stroboscopic Visibility Measure (SVM): $SVM = 1$ means that the observer detects stroboscopic effects with a probability of 0.5

The fact that temporal light modulation is visible, it cannot be concluded that it is not acceptable or that it causes adverse health effects. To define modulation limits, the relation between Pst^{LM} and SVM respectively and acceptability and negative health effects have to be studied. Proposed limits for Pst^{LM} and SVM have been published by National Electrical Manufacturers Association [2].

Perz et al. showed for different SVM between 1.0 and 2.3 that acceptability is high, although stroboscopic effects are clearly visible [3]. Investigations on effects related to human health give evidence that flicker at low frequencies (10–30 Hz) can cause migraine attacks [4]. Temporal light modulation at frequencies between 5–10 Hz may induce an epileptic seizure of patients suffering from photosensitive epilepsy [5]. Less has been reported on adverse health effects for higher frequencies. Wilkins et al. performed studies in the late 1980’s focusing on temporal light modulation of fluorescent lamps driven with magnetic ballasts (modulation frequency 100 Hz) and with electronic ballast (32 kHz) [6]. In one out of four test groups they observed the incidence of headaches was reduced by switching from 100 Hz to high frequency, but the difference between the conditions was ‘marginally significant’. In a later study using similar modulation frequencies the result could not be reproduced [7].

As adverse effects and acceptability of flicker (modulation frequency < 80 Hz) are well known and the limit of $Pst^{LM} \leq 1$ is commonly agreed, we will further discuss the topic of stroboscopic effects (modulation frequency > 80 Hz).

Temporal Light Modulation Above Critical Flicker Frequency (CFF)

If light is modulated with a frequency lower than CFF (typically 80 Hz), the neurons in our eyes are able to follow the intensity changes and a sequence of brighter and dimmer stimuli will be visible. If modulation frequency is above CFF the neurons cannot adapt to the fast intensity changes any longer and the stimulus becomes a mean value [8]. In consequence, light modulation will not be visible any longer, as long as the object is not moving.

If the object is in motion, a stroboscopic effect (Example see **Figure** 1) may occur. This means an object may be seen as multiple objects in different locations. The effect will only be visible with sufficient movement (speed), sufficient contrast and sufficient illuminance. If the movement lasts for a longer time the effect will be perceived consciously. In the study of Perz et al. [9] a rotating disk was used to study this effect and to develop the Stroboscopic Visibility Measure (SVM). For short lasting movements the stroboscopic effect may not be consciously visible but whether the effect can be seen or not is very different from whether it has effects on health.

To appraise the effects of temporal modulated light on humans at frequencies above CFF we have to answer the following questions:

- Are stroboscopic effects visible?
- Does it affect acceptance or mood?
- Can adverse health effects be observed (short term and long term)?
- In addition we can ask: How are the answers to the above three questions correlated to SVM?

The answer to these three questions may be different for different environments. In the rotating disk (Example see **Figure** 2) environment of Perz et al. [9] stroboscopic effects may be visible at modulated light with a certain SVM. With the same light source no stroboscopic effects may be visible in an office environment as movements are slower and last only for a short time, as contrasts between object and background are small. Working in the office with modulated light at a certain SVM may cause no headache but observing the rotating disc for several hours may cause headaches.

Two recently published studies try to give answers to some of the above questions.

Study of Sekulovski et al. [10]

The goal of the study was to explore the effects of long-term exposure (13 weeks) to temporal modulated light in respect to mood and adverse health effects.

The study was performed in two spaces, an open office space and an electronics workbench. People performed their normal daily activities and filled out a questionnaire regarding mood and health every morning and evening. 30 LED fixtures per working space provided temporal modulated light, switchable between SVM = 0.47 and

Figure 1: Impression of the stroboscopic effect when waving a hand

SVM = 1.34. The lower SVM was used in the reference situation and the higher value for the intervention. Change between reference and intervention took place on a weekly basis and for two weeks, on a daily basis. The number of participants (46) and the duration of the study (13 weeks) were determined by statistical means to have a chance > 90% to detect a 5% increase in headache probability.

The ages of the participants were between 36 and 65, about one third of them over 50. There were 42 male and 4 female participants who completed 2813 surveys over the 13 weeks.

Only less than 1% of the participants reported severe problems with eyestrain, vision problems or headache, 4%–9% reported moderate problems, in both reference and intervention conditions. The increase of moderate problems over the day was 1%–2% and significant, the increase or decrease of moderate problems between reference and intervention was less than 1% and not significant. Participants rated levels for six different moods based on a questionaire. No significant change of mood levels between reference and intervention could be detected.

Conclusion I

The study investigates long term effects in environments representative for general lighting applications. The study doesn't give an answer to the visibility of stroboscopic effects. Even on long term there is no effect on mood expected using temporal modulated light with SVM = 0.47 or with SVM = 1.34. There are also no adverse health effects expected regarding eye strain, vision or headaches. The results are trustworthy as the paper is peer-reviewed.

Interim report NRC-CSTB [11]

The study has been performed in two different locations, in Ottawa, Canada (NRC) and Saint Martin d'Hères, France (CSTB). In both locations five commercial LED lamps were used with SVM ranging from 0 to 3. The experimental setup was similar in both locations. It consisted of a rotating disk experiment similar to that of Perz et al. [9] and a metronome experiment to examine stroboscopic effects with horizontal and vertical tasks. The report is based on 36 participants split evenly between both locations. Most participants were between 18 and 29, 3 of them

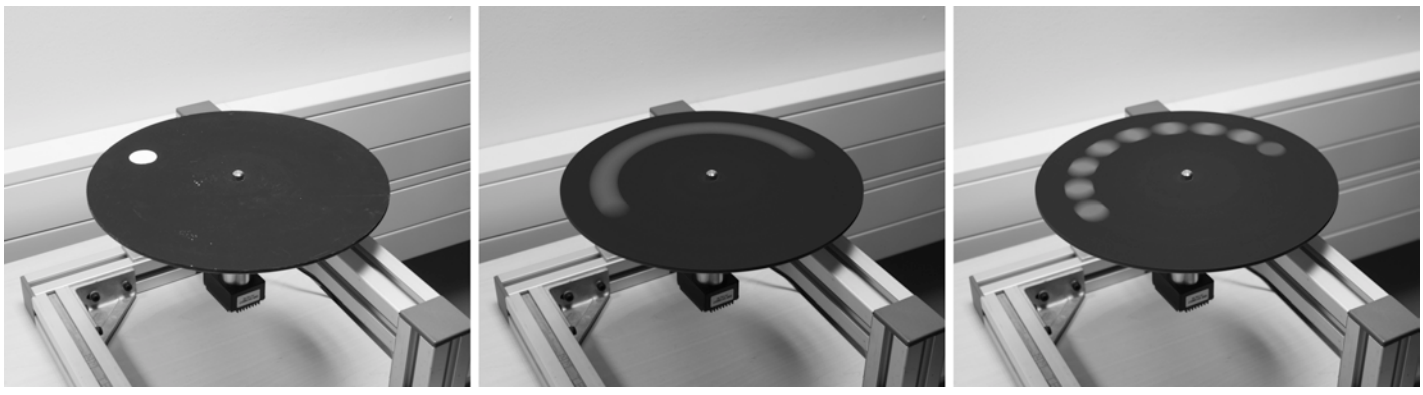


Figure 2: Rotating disk in three states

between 30 and 39. Each participant completed ten trials. In each trial the five lamps were presented in random order.

The results show a clear correlation between visibility of the stroboscopic effect and SVM. For SVM $\leq$ 0.4 the effect was only visible in 10% of the trials, at SVM = 0.9 it was visible in 63% of the trials, for SVM = 1.4 it was visible in 90% of the trials and always visible for SVM = 3.0.

When we look deeper into detail, there are things that stand out. At SVM = 0.9 the effect was visible in 25% of the trials in Canada, but in 70% of the trials in France. Looking at the other lamps we find that there is always a difference between the locations, visibility is always detected more often in France. Is this due to statistics or differences in the experimental setup? The report doesn't mention this, leaving the question unanswered. Other questions are: Why is a stroboscopic effect visible in 10% of the trials even at SVM = 0 (no temporal modulation)? Why is the effect at SVM = 1 only visible in 10% of the trials for 50% of the participants (definition of SVM = 1: Visible in 50% of the trials for 50% of the people)?

Detection of the stroboscopic effect on the metronome doesn't show a clear picture. It is nearly constant at 30% for SVM $\leq$ 0.9 and then increases to 68% at SVM = 3. Again there are big differences between the experiment in Canada and in France due to different positions of the metronome in the two locations. Therefore it doesn't make much sense to give mean values.

Participants also rated acceptability for each light source in terms of comfort, pleasantness and annoyingness. The results show no clear trend – decreasing acceptance with increasing SVM, but increasing acceptance again with the highest SVM! Statistical analysis of the data shows that acceptance is not significant.

Conclusion II

The study investigates short term effects in an environment that is not representative of general lighting applications. The report shows that visibility of the stroboscopic effect increases with SVM and can be taken as proof of [9], although the results tend to show lower visibility. It also proves that acceptance of the temporal light modulation is not significantly correlated to the SVM-value (in the range between 0 and 3). Eventual adverse health effects have not been studied. The preliminary results of the interim report leave several questions open even in the fields of investigations. To date, the final report has not been published and not been yet peer-reviewed.

Final Considerations

Limits for temporal modulated light shall assure light quality for acceptability of lighting and to avoid adverse health effects. Studies show that although stroboscopic effects are visible even at the lowest SVM-values, there is no significant correlation between SVM and headaches, eye strain and vision problems for SVM < 1.34. There is also no significant correlation with acceptability for SVM < 3.0. Hence, there is no evidence that the limit for SVM should be set below these experimentally proven values. ■

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ABOUT THE AUTHOR

Dr. Günther Sejkora: Dr. Sejkora received his PhD from the University of Innsbruck after studying physics, IT and mathematics. He spent more than 20 years in the Research & Development department at Zumtobel Lighting and then went on to start his own company, "items" where, together with industrial partners, he has carried out more than 50 R&D and technology projects in the fields of LED lighting and lighting controls. He was Managing Director of the Kompetenzzentrum Licht GmbH from 2010 to 2015 and is currently the Research and Innovation Manager at Luger Research e.U.

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Tech-Talks BREGENZ
Dr. Christoph Wächter, Senior Scientist at Fraunhofer IOF, Germany

Dr. Christoph Wächter

Dr. Christoph Wächter received his degree in physics and the title of Dr.rer.nat in Theoretical Physics in 1981 and 1987, respectively, from the Friedrich-Schiller-University in Jena. He has been active in the field of photonics since 1983 when he joined the Physics Dept. at Jena University and started his research activities in the area of mulitlayer and waveguide optics, with particular emphasis on non-linear guided wave phenomena. In 1992 he joined the micro-optics division of the Fraunhofer Institute for Applied Optics and Precision Engineering, Jena, where he is concerned with the design of integrated optical micro-optical devices.

Research topics have become more important with LEDs and LED lighting micro optics and freeform optics. A new approach based on an IP for a fly's eye condenser from 1928, filed by Zeiss Ikon AG that extends possibilities and allows for new applications was presented ,at LpS 2019. The jury was so impressed with the paper that it won the Scientific Award 2019. Dr. Guenther Sejkora and Arno Grabher-Meyer from LED professional talked to Dr. Christoph Wächer, co-author and presenter of the paper about his approach, his career and work. Dr. Christoph Wächter is a senior scientist at Fraunhofer IOF.

LED professional: **First off, we'd like to congratulate you and Peter Schreiber on winning the LpS 2019 Scientific Award.**

Dr. Christoph Wächter: Thank you very much.

LED professional: **What did you think when you heard that you won?**

Dr. Christoph Wächter: We weren't expecting it at all, so we were very surprised. It was a great feeling – a great honor. What was presented in the paper was an irregular fly's eye condenser and now we have the means to extend the field of applications that we can address with those micro-optics for illumination and potentially for imaging tasks. So, it was an honor and a surprise and it encourages us to go further in this direction. A great day!

LED professional: **The award is mainly for the authors, but it is also meant for the whole team. I believe you worked with a big team, so do you have an idea of how you're going to celebrate with them?**

Dr. Christoph Wächter: I imagine that we'll go into the lab and show them the award and the certificate and tell them, "We did it!" Peter said yesterday that we'd get a big tent and celebrate together. And you're right – it was a very big team that contributed to the contents of this paper – so many, that I can't list them all. There were people that contributed the central idea, did numerics, those that made sure the technology was feasible, someone made the ray tracing, I contributed parts for generating masks if needed, a group of technicians were responsible for the reflow master. Then there was the person responsible for the UV-LED-lithography and all the engineers that were responsible for all the modifications of the exposure regime, the design engineers, and so on and so on. There are just too many to name them individually.

LED professional: **What impressed the jury was the entirety of the work you did, starting with the analysis of the state-of-the-art and then formulating the research question of what you wanted to achieve. You then went on with the theoretical calculations, the simulations, mastering, production of the demonstrators and finally the measurements. It was a complete work, and one of the reasons the award went to your team. Today, it seems, that people only see one aspect of scientific work and you saw the entire work. Fraunhofer is well known but IOF isn't. Could you tell us what it is and what the main topics of IOF are?**

Dr. Christoph Wächter: IOF is one of about 70 Fraunhofer institutes. Fraunhofer IOF, the Institute for Applied Optics and Precision Engineering was founded in 1992 – not long after the reunification of Germany. The idea was to keep knowledge and competences of colleagues from university, academy of sciences, Zeiss R&D and to group them together in Jena. The founding consortium, under the guidance of Professor Karthe, spoke with Fraunhofer in Munich, and they decided to start it as an institution, and not an institute, giving us five years to get our finances in accordance with the Fraunhofer rules – to earn our living by carrying out projects with not much basic funding. Three years later we were able to change our standing from institution to institute, and since then we have been constantly and rapidly expanding. We started with sixty people and now we are two hundred and fifty. Our facilities were expanded in 2002 and recently we had to enlarge them again.

We are active in quite a few different fields, and as the name says: applied optics and precision engineering, it is really widespread. But it offers the chance, on the one hand, to look at micro-optics, and on the other hand, at complex assemblies which may contain micro-optics or could be larger telescope elements. So the range we are looking at meanwhile expands from space applications down to micro-optic or nano-optic elements that are used in telecom or for sensors. Other applications for microlenses are cameras or miniaturized microscopes. It's a very broad range that is backed up by a lot of different technologies. So we have technologies for a nano-fabrication; we have a very specific tool for electron beam lithography; we have precision manufacturing: single point diamond turning, a construction department that is able to make lightweight assemblies, we are active in the field of 3D structure generation by metal printing or printing polymeric materials. The range of technologies we have in house is really wide; I just can't name all of them here.

LED professional: **I wasn't aware of the fact that Fraunhofer manufactures a lot of different optics. I know Fraunhofer more as an institute that does research. How much manufacturing do you do?**

Dr. Christoph Wächter: The usage of English words can be misleading in this case. When I say manufacture, it usually means the fabrication of demonstrators. We develop a technology, we develop

UV-LED-Lithography-tool for master generation. © Fraunhofer IOF

the means to fabricate micro-optics but we aren't capable of doing any type of mass production. And, as a matter of fact, Fraunhofer is eligible for basic funding and to produce commercially would be in contradiction to that. It wouldn't be compatible with any competition in the worlds of R&D and technology development. But in certain cases we develop machines or technologies running on machines – either machines developed by us, or machines being available on the market – and bring those machines or technologies to maturity. In consequence we transfer the process or the machine plus technology to customers. If they are interested in entering a new field of technology and we can provide appropriate technologies developed by Fraunhofer, we establish a spin-off.

Many years ago we made a lot of effort in the field of graded index lenses. When we started in the 90's we had some activities running in the field of telecommunication. And with ion exchange you can make nicely graded index waveguides buried beneath the surface. You can use them for splitters, for arrayed waveguide gratings and the like. The technology was mature at the end of the '90's. Further basic research work or basic technological development was not seen. It worked and we were able to think about making a spin-off company. The company makes graded index rod lenses, some wave-guide components if necessary, and it's really nice. A few weeks ago I had a call from a former customer of ours asking if he could have the same components that he had in 1994. After looking up what we had done for him back then, I called him back and told him we were not able to produce the same components anymore but our spin-off company could do it. This is an example of long-lasting success stories with spin-offs.

We have spin-offs in the field of layer deposition, e.g. for interference layer systems in the extreme UV at 13 nanometers for use in microelectronics production tools. Also for this technology we did the development in house.

We do demonstrators; we develop technologies and do some production in case nobody else can do it. In the field of applied micro-optics we have a transfer directly to the industry with equipment that's available on the market. With our special knowledge we help them to bring those technologies to mass production on their own premises.

LED professional: About twenty years ago I saw the first optical microstructures at the research fair. At that time, practically nobody knew what micro-optics was. Today they are much more important. In the final selection for the LpS Scientific Paper Award, four of the nine papers dealt with optical microstructures. Do you think that the increasing importance of optical microstructures is because of the technology we have today to generate microstructures or is it really an advantage for certain applications?

Dr. Christoph Wächter: They definitely go hand in hand. We have the capabilities to produce micro-optical structures, and we have possibilities with micro-optical structures, which would rarely work with bulk optics. A simple example of what we were talking about yesterday in the lecture: If I'm going to shape light distributions – first to collimate, then to make it efficient, then to look for higher brightness of the sources. You can scale it either on 3D, but then it gets bulky. Or you can have enlarged power by only enlarging it in 2

dimensions with some kind of micro-optics plus fly's eyes condensers. New possibilities are based on what we have from, basically, the semiconductor equipment industry, lithographic tools, mask aligners for replication etc.

Nowadays we also have nicely evolving tools for 3D printing in qualities that are required for optical applications, and of course, the possibilities arise with the design capabilities, too. If you do micro- or nanostructures you have to have in mind that it isn't just standard, simple ray tracing that you can apply. You have to have more tools. You have to mind diffractive effects; you must be capable of using wave optical and numerical design methods, methods to combine them and to look at the structures as a whole.

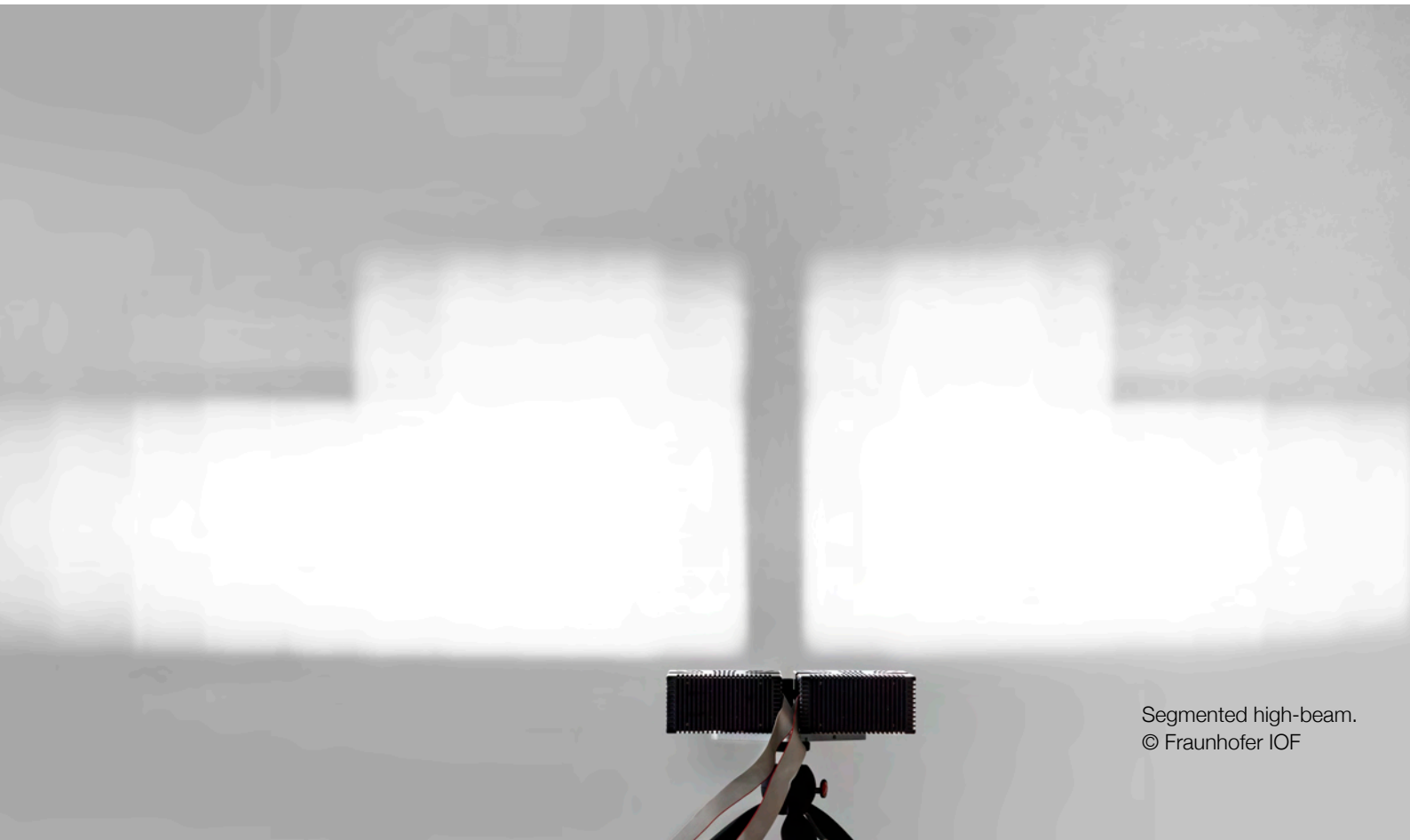
If you are capable of this it's a nice evolving thing. The thing that optics could profit from, especially in the field of waveguide optics, are developments that basically stem from the semiconductor industry. Getting more precision in the preparation of tiny structures can be used nicely nowadays for micro- and nano-optics as well. With the e-beam lithography we have in the house we can lamellar slices and gratings with 100 or 150 nanometers structure size and suitable depths. If we didn't have the large development field from the semiconductors, optics would not have had the force to drive it. Fortunately, though, we have the possibilities, and people are more and more aware of the fact that with the new principles they can get better and cheaper components, at least on a mass production scale, and they can get new features for the optics.

LED professional: When I look at the other papers that describe microstructure optics, the authors take a very direct approach using the micro-optics as a secondary lens and just calculating for the individual beam that they want going in a certain direction then mainly calculating the angle of the surface and then forming a complete optic. You use your irregular fly's eye condenser differently, using the micro-optics as tertiary optics. Could you tell our readers what you see as the advantages for your approach?

Dr. Christoph Wächter: Basically, I guess the approaches are not that different. Not all authors use the same nomenclature naming primary, secondary and tertiary optics. Of course there are different approaches, especially as we saw yesterday in a lecture, with diffractive elements we usually don't use collimation in between. You aren't really forced to have collimation in between but you may have it. What we intended to have was a clear development after what we had before. In fact the paper or presentation we made was a kind of historical review.

When we first received higher power light emitting diodes directly from Osram in the late 1990's, they told us not to waste the photons. We had small sources with almost Lambertian characteristics. So, how could we get the light out of it: potentially with some reflectors in the ceramics or potentially the dome (which isn't the best version for all cases). Then we had to collimate the light and there we saw that it wasn't that straightforward because it wasn't really a point source and we had some dimensions that we had to adapt, like the sizes of the collimator, etc. Finally it was collimated but not homogenous. So then we had to figure out how to homogenize it. At that point we went back to what had been invented around 1935 in Jena: the fly's eyes condenser, and we were happy with that.

Before that we had developments in the field of waveguide optics. Waveguides were made from polymers, and starting from that technology we were able to provide micro lenses with a reflow technique. So we tried the approach of fly's eyes condensers and this gave us a homogenized output of LEDs. In those



Segmented high-beam.
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times we had monochromatic LEDs so the next step was to add all the colors – RGB to make it white. At that time nobody had a white LED. We saw that we could easily homogenize it. Through good luck we saw that we could also use it for imaging as well. We turned it on and saw that more was possible. That's when we got the idea of the chromium mask we could use for structured illumination. One of the shortcomings was that we lost brightness and we weren't supposed to waste the photons. It was a long process and we realized that we could do more if we had more technological possibilities that would allow us to do more than reflow lenses. They are ideally spherical or slightly aspheric but there isn't much more one can do.

Then we came along with laser-lithography with a commercial machine. We learned about what is possible and what could be done better. We had a very clever young man who made a concept. So we developed the first machine for the UV-LED-lithography, which enables us to create particular variable freeform optics. If you define a freeform element it is usually a surface that is not rotational symmetric. And if you use a rectangular piece of a sphere that does not contain the center, it can be considered to be an aspheric element. It's not rotational symmetric – and it is usually hard to fabricate. Using UV-LED-lithography we could fabricate these types of structures and we were free to think about what we could use as the basic elements of the iFEC (irregular fly's eye condenser). As it was presented yesterday, it was an historical review showing how new possibilities and new ideas can expand your mind. If you want to get more into detail, of course it would require another lecture of more than an hour just to get a basic idea of how it works.

LED professional: **In your presentation you mentioned the BMW Welcome Light. And as the demonstrators you showed the low beam and high beam headlights. We know that the Welcome Light has already been copied by Chinese manufacturers, so is there a specialty in the headlight that can't be copied easily?**

Dr. Christoph Wächter: First of all, for Fraunhofer it's clear that if you have new inventions, you have the IP as well. If something like the BMW Welcome Light

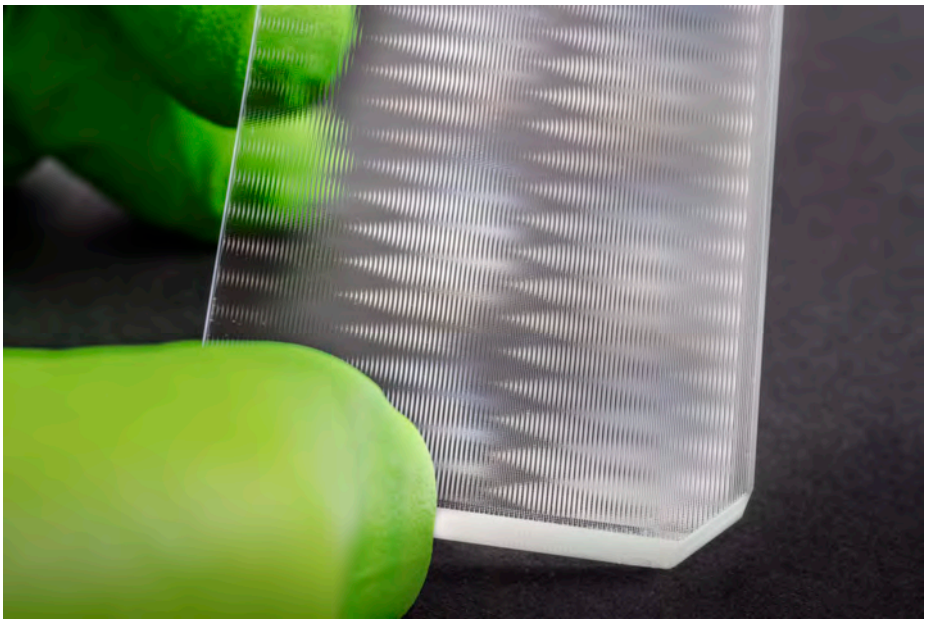


Figure 1: Replicated high-beam micro-optics (iFEC structure). © Fraunhofer IOF

Carpet is copied abroad and brought to market abroad, we can't do that much. On the other hand, there are also Chinese companies coming to us, asking for licenses. So in regards to the headlight, the principle approach was as usual to first secure our IP and then to talk to people about what we could do further and how it would work in future applications.

LED professional: **Protection can be taken in different steps. On the one hand, you can protect the idea and on the other hand, it might be manufacturing is more complex and harder to copy and that has to be protected.**

Dr. Christoph Wächter: Firstly, we protect our ideas as a basic approach. And here it is reasonably easy to detect it if they have been copied. Secondly, we know how complicated it is to start production and low quality copies wouldn't have very much acceptance on the market. Production tools are not explicitly specific for our application, so we count on the fact that we have some advantage with our technology.

On the other hand, customers will sometimes ask Fraunhofer if we can transfer the technology or equipment over to them as well, which can be the basis for a fruitful cooperation. Our basic tasks are coming up with new ideas and then developing new technological tools. It's R&D work, so we aren't too worried about IP processes. Of course if something is really successful, IP brings income to Fraunhofer. This income can be spent on new projects in new fields and thus is most welcome. But of course here I speak for myself. I'm not worried that much – knowing that there is the legal department at the headquarters in Munich.

LED professional: **Micro-optics has a lot of advantages – especially the size. According to one of the lectures, yesterday, there are also disadvantages like the stray light generated at the steps between the structure elements. Do you have the same problems with your approach?**

Dr. Christoph Wächter: Stray light is a severe problem. If we have a smooth lens profile from reflow – if you work with the iFEC you can have lens profiles that have steps in the height – usually we have the next neighbor directly adjacent to it. But to produce sharp vertical edges is really challenging. To get a 90° edge is almost impossible because if you make a UV polymerization there you have some diffusion and some minor divergence as well. You'll only be able to make about 85°. Light coming on these steps causes stray light. And this is generally a problem.

We can suppress stray light to some order with clever designs and clever technology. If we do the iFEC design process we can formulate boundary conditions and minimize jumps. Developing the high beam for the

headlight we did two attempts. For the first attempt we did not use the jump minimization because it seemed to be easier for the definition of the master and the production process. But we saw a lot of stray light where we were more or less sure that it was caused by the steps. So we made the next attempt. It was a learning by doing process. We don't like a chromium mask beneath the structure for stray light suppression. But if we have an area that is prone to stray light then we can reduce this with some minor stripes of chromium.

Here it doesn't really matter if we lose some efficiency by the chromium. If we shaped it accordingly we would lose about the same as we miss due to the stray light, about 1.5% in total. Stray light always has an impact on optical functionality. But with a clever combination of design and technology one can avoid such unwanted effects.

LED professional: **I have two questions about that: The problem starts with an incomplete collimation, is that right? The second question is: Can you create the same effect with a gradient optical refractive index instead of geometric structures?**

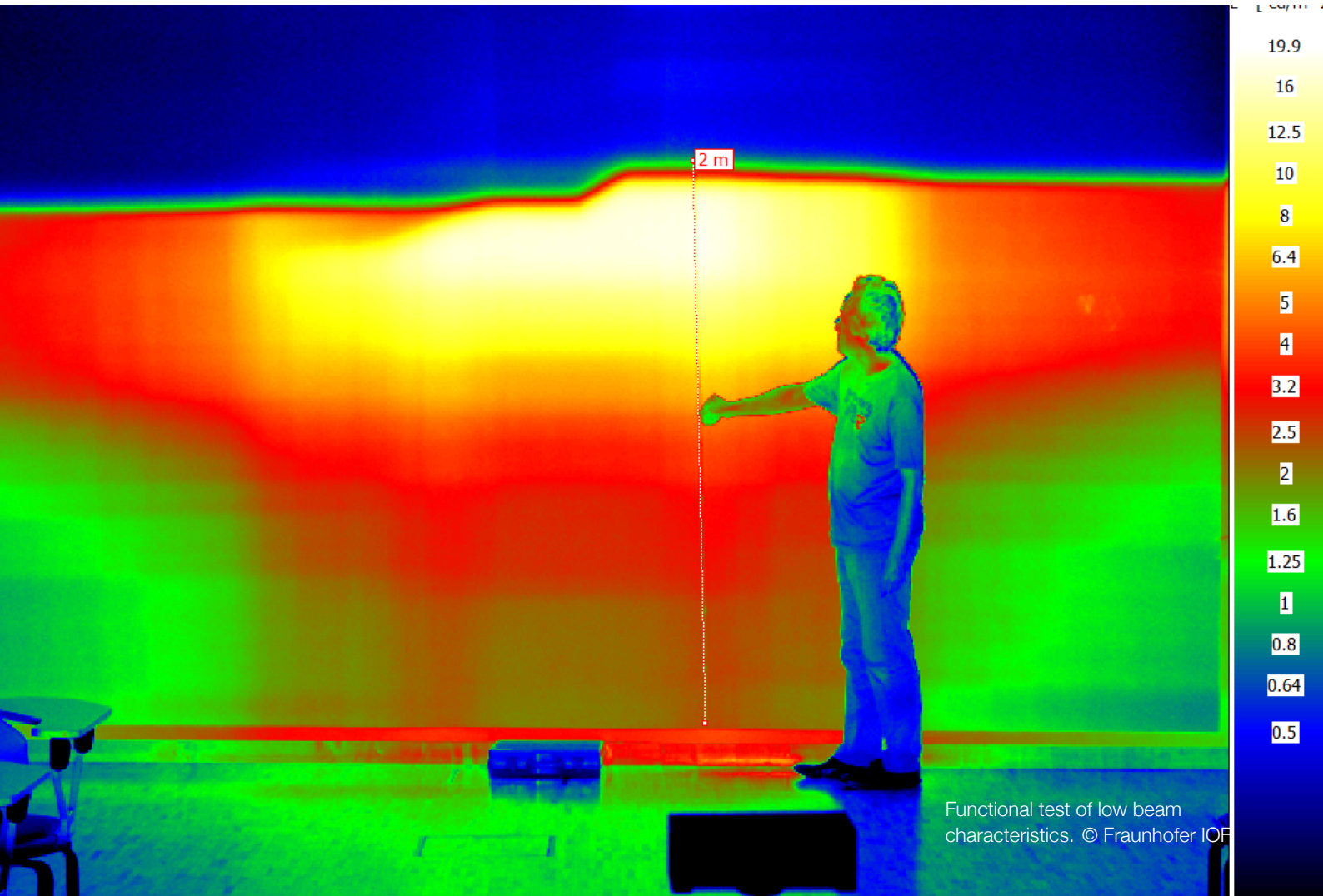
Dr. Christoph Wächter: In answer to your first question: Yes. This is the basis of the fly's eyes condenser. In practice, the input to the fly's eyes condenser is a bundle with limited divergence. A perfect collimation would require complete parallelism, i.e. due to etendue-conservation it would require to have very large diameters. The acceptance angle for such fly's eyes condensers depends on the distance between the lens arrays, the focal length, and the lens height. From this we get the numerical aperture – what is accepted and what is leaving the exit lens array of the fly's eyes condenser regularly. And of course, if we have some light that isn't sufficiently collimated we have the problem with stray light generated already at the entrance lens array.

The second question: shaping the refractive index in the dependence of the local coordinates of the surface is a very nice idea but is hard to achieve. Usually you have one and the same material and you make the refraction due to the bended surface. Of course you can do refraction by using a locally varying refractive index but how can it be generated? Using slightly different materials at different positions we dealt with before at Fraunhofer with the graded index media fabricated by ion exchange. But with this technology we cannot achieve the same effects as with different surface radii as we use, for instance, for the microlenses.

What we can do with gradient index technology are other things. It's suited for gradient index rod lenses or buried waveguides or something like that, but we wouldn't have any idea how to transfer it to generate iFEC structures. Furthermore, to realize a locally varying effective index we need lithographic structure for each sample, which is not that cost effective.

LED professional: **In your lecture you talked about automotive applications of the iFEC technology. Do you already have ideas or are you even transferring this technology into general lighting?**

Dr. Christoph Wächter: This was one of the basic reasons that we came to the



Functional test of low beam characteristics. © Fraunhofer IOF

A number of members of the iFEC-team. © Fraunhofer IOF

LpS. We just finished a spotlight project, which was funded by Fraunhofer internally and we had good results. Now we are looking for follow-up projects together with industrial partners and we want to show what we could achieve. Of course, when we started the project we had a lot of different applications in mind, ranging from shop lighting to individual lighting, general lighting or advertising, even applications in the field of health – like luminaires for operating rooms. Now we can show potential customers what is possible and also tell them that we are willing to serve real world applications where our ideas can be used fruitfully.

LED professional: Yesterday I saw that you had a good discussion with a potential customer about all the options.

Dr. Christoph Wächter: That's for sure! We have good contacts and projects within the field of the automotive industry. But we are here at the conference to make other contacts in other industries as well. The Welcome Light Carpet is a fancy product. Other carmakers could make something similar. But we feel like we could do more in other application fields. So a conference like this one is just the location for the right audience. We get to know other people with other ideas that can be adapted to other applications. It's also great to be able to talk to other lecturers or individuals at their booths so we can see what they can do and vice versa. We hope to be able to expand our field of applications by far.

LED professional: In that case we can only hope that the Scientific Award will help you to become more well-known and bring you into new fields of application and new projects. Good Luck!

Dr. Christoph Wächter: Thank you! ■

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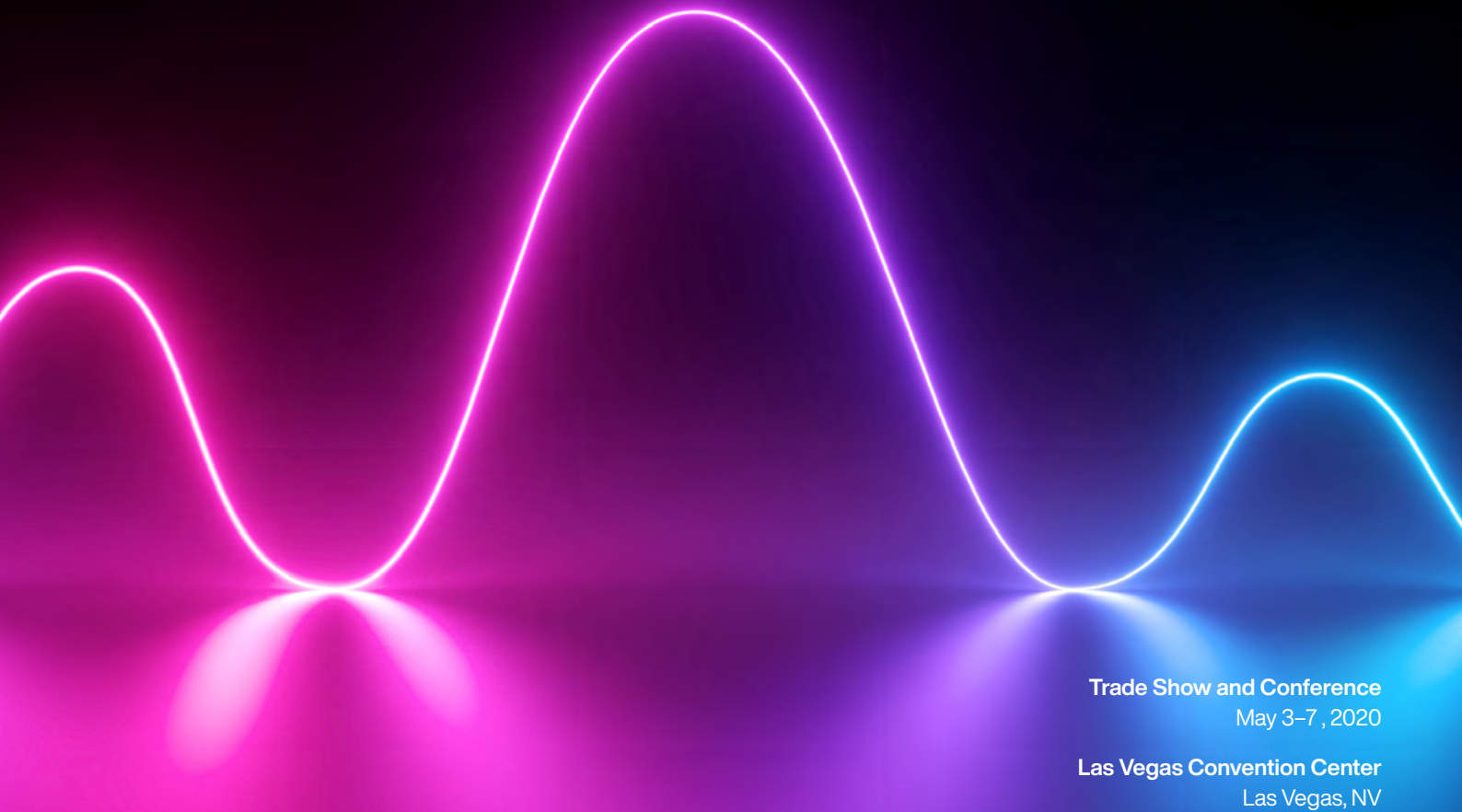

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LED Innovations for the Improvement of HCL Luminaires

Human Centric Lighting is not a new invention but, rather, it has become more important than ever with the introduction of LEDs. While LEDs made lighting systems more complicated, the correct application offers impressive new opportunities to better accommodate the needs of users and applications. Menno Schakel, Technical Marketing Manager at Nichia, describes an important innovation for HCL that received the LpS Sustainability Technology Award at the LpS 2019 in Bregenz.

Human Centric Lighting (HCL) is currently one of the primary drivers of lighting innovations and tunable (white) solutions play a major role in enabling HCL. Whether it is to simulate the changing color temperature of sunlight during the day, or to let the user pick their own preferred light, the color changing aspect of the light is at the heart of it.

The conventional way to achieve a tunable white solution is to use separate light sources of different color temperatures. In this paper we will introduce new innovations which support HCL luminaire design by having the tunable white solution in one light emitting surface (LES). Having one LES, but still two separate controllable channels, allows for freedom of design of luminaires previously difficult to achieve with tunable white. Having a single LES reduces the need for additional optics or diffusers while still maintaining a good (color-) homogeneity.

We have designed two single LES tunable white LED's. The Chip-On-Board (COB) style package enables tunable white spot solutions which before were only realizable using Direct Mountable Chip or Chip-Scale Package (CSP) solutions. Having a small tunable LES available in a ready-to-implement solution, without having to make a peak-design PCB every single time, will enable luminaire manufacturers to more easily expand their tunable white portfolio and hopefully inspire many new designs.

Introduction

For a long time, the driving force for innovations in the lighting industry has been the efficiency of the product. The efficiency of the light source(s) has one of the biggest effects on the final efficiency of the end-product (e.g. a luminaire or lamp). The latest market trends and innovations clearly show a changing market, and Human Centric Lighting (HCL) is at the core of that change. HCL is not a single concept but encompasses several theories and concepts and all of them revolve around using lighting to improve the well-being of people.

Ever since humans have walked the earth, we have been accompanied by the sun. We wake up in the morning because of increasing light intensity and at night we go to sleep as the sun sets. At least that's how it was until the invention of the electric light. However much our current, dynamic way of life might want to change things, the daily rhythm is built into us. Spending our days in dark, gloomy and poorly lit offices, our bodies still try to follow daily rhythms but withoug the external stimuli of the changing light from the sun. This is not an easy feat.

One of the concepts in HCL is recreating the natural daily lighting cycle, called circadian lighting. Simulating the daily lighting cycle of the sun, meaning bright blue light in the morning, neutral day light at noon and warmer more relaxing, less bright light in the afternoon and evenings and of course the absence of light at night [1].

Human Centric Color Tunable Lighting

Tunable lighting products able to create circadian lighting have been available on the market for a few years already. Several manufacturers have color tunable or tunable white products on the market. The technology used in such products is the use of multiple colored light sources, either various single color light sources, or two or more white colored sources. The first is referred to as a color tunable product, the second generally as a tunable white product. The area bounded by the color points of the separate sources is referred to as the color gamut of the product (illustrated by the highlighted grey area in **Figure** 1), similar to how the color gamut of a display is the area bounded by the single colors of the display elements.

Since the purpose is to simulate the daily light cycle, a color tunable solution is not ideal. As color tunable light sourses are desinged with single color or monochramatic sources, sometimes supplemented with a single white source, the color fidelity and color rendering of these sources do not match up against a current, normal whicht lighting product. A red, green and blue (RGB) color tunable solution for which the color gamut is shown in **Figure** 1 with a color rendering index (CRI) below 80 when generating white light does not make for very comfortable light in an office or home environment. And since the trend is an increase in color quality requirements, RGB solutions are far from desired, let alone allowed by current or future building regulations.

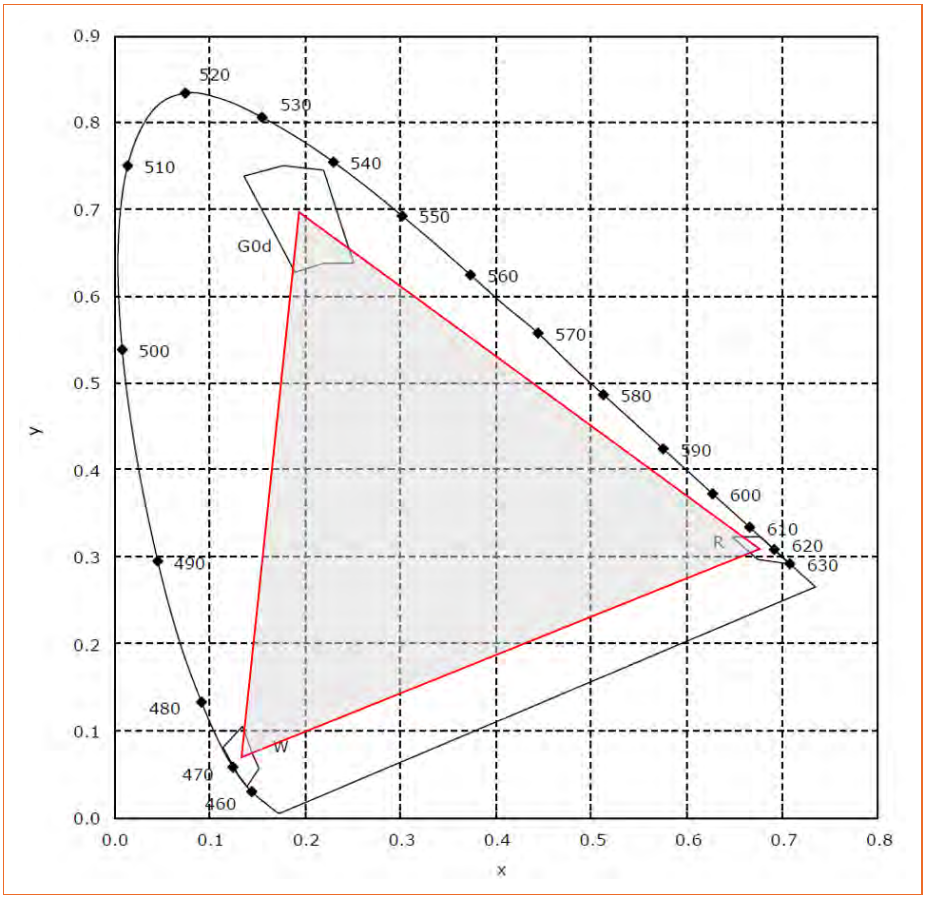

Figure 1: Color gamut of a Nichia RGB LED (Part No. NSSM240AT)

Tunable white solutions offer a great benefit compared to color tunable solutions, in that their base lighting components consist of white light sources. The tunability comes from adjusting the ratio between the different whites. The base whites can have CRI values which are far greater than can be achieved with an RGB solution and the light from a tunable white solution will have far superior quality.

Another advantage of tunable white solutions when used in a circadian lighting application, is in the electronics. By having only two sources, the electronics only need to be set with a ratio-driving to generate light with a certain color point or color temperature. In an RGB solution, the electronics are more complicated because it involves a triple variable calculation and is prone to show variations between products. Calibration of the color of the product during manufacturing and temperature, age and forward voltage corrections implemented in the driver or integrated circuit are time intensive and expensive but are necessary precautions to reduce variations between RGB products. Smart RGB is a future solution that can reduce the effort to control the inherent color variation of color tunable products, but this technology is still in development and not yet ready for mass market products. Only having two separate sources to drive, instead of three, and both using the same LED chip material, having similar electrical behaviour, reduces design effort and cost of electronics.

Two New Tunable White Solutions

To support the innovation of luminaire designers, NICHIA has developed two tunable white solutions.

A tunable white COB and a tunable white mid-power 3030 package (2-in-1) an image of both shown in **Figure** 2.

Figure 2: Nichia's tunable white solutions. COB package (Left), mid-power package (Right)

Both products are tunable white solutions with the additional benefit of having a single light emitting surface (LES).

Single LES Advantages

As discussed before, tunable white products are not new in the market. Single LES tunable white LEDs are a new innovation and will enable new designs of HCL luminaires.

Improved color mixing in a smaller space is the main benefit of a single LES product. The closer the LES of different colored light sources are, the better the color mixing of the sources. In the new LEDs, the distance between sources has been reduced to the point where they share the same LES. In the mid-power package, the LES is even indistinguishable from its non-tunable sister products. One has to look at the backside of the package, at the footprint, to make the distinction between the tunable and non-tunable version as only the latter has a pair of cathodes and anodes (**Figure** 3 Bottom) to enable separate driving of the two channels.

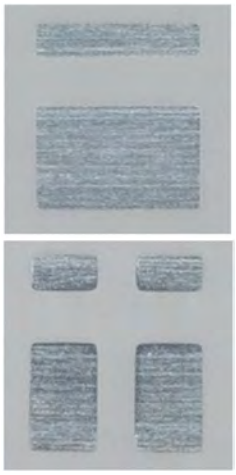

Figure 3: Footprints of 3030 mid-power packages. Standard package (Top), 2-in-1 package (Bottom)

Good color mixing can be achieved with multiple separated sources as well. By using a diffuser as an optical exit surface, a single LES is simulated. There are several disadvantages with this approach. First, the diffuser will cause additional efficiency loss in the product due to absorption in the diffuser itself and additional unwanted back reflection. Second is the additional space required. To properly mix the light, the spacing between the diffuser and the sources is directly related to the spacing between the LES of the multiple sources. Alarger horizontal spacing between the sources, leads to a larger optical distance between the light sources and the diffuser to keep the same quality of color mixing. Luminaires designed with single LES products can be thinner due to smaller optical distances.

Mid-power Package, "2-in-1"

The small single LES design of the mid-power package makes it well suited for light-guide designs and especially for edge-lit solutions. It is simpler to couple the light into a light-guide and keep a consistent light mixing effect with a single LES. With the mid-power package, the canvas or blindfold around the fixtures' LES can be reduced as illustrated in **Figure** 4.

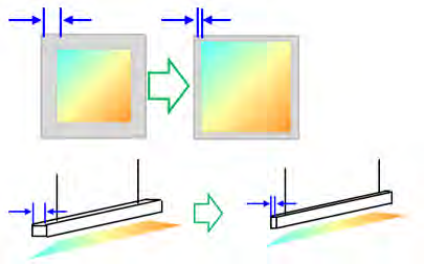

Figure 4: Reduction of blindfold for edge lit solutions (Top), reduction of size of pendant solutions (Bottom)

Fixtures currently designed with 3030 mid-power packages and relying on secondary optics can easily implement the 2-in-1 mid-power package, without an expensive redesign of the product. The external dimensions and LES are the same as the current generation of mid-power packages.

A Closer Look

The cool white light in the 2-in-1 is generated the same way it is normally generated in white LEDs; a blue chip (① in **Figure** 5) and a yellow/green phosphor, usually YAG. This phosphor is contained in the silicone resin, as indicated by ④ in **Figure** 5, which is covering both chips. The second chip (② in **Figure** 5), which is also a blue InGaN chip, is covered with an additional (red) phosphor and is generating the warm white light.

The combination of cool white and warm white in the same package (③ in **Figure** 5) creates an actual single LES including both sources, unlike other similar concepts where even though the color-tunability originates from a single package, there are still two distinct LESs due to the two separated cavities. An example of a package with this design is shown in **Figure** 6.

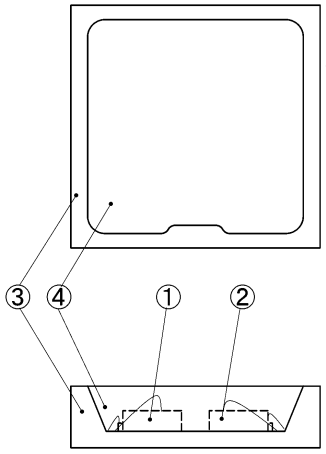

Figure 5: Internal structure of the 2-in-1 package

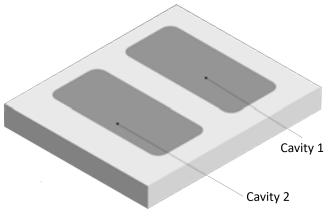

Figure 6: A tunable LED concept in one package with two separated cavities, one for cool white and one for warm white

Chip-on-Board, "Tunable White COB"

In a spotlight design, a diffuser is highly undesirable. A diffuser creates an effectively larger LES, and therefore reduces the efficiency and effectiveness of the spot. For a spot design, the smaller the LES is, the more freedom in optical design is available. Due to the law of conservation of etendue [3], whenever light contained within a certain solid angle ('beam angle') passes through a diffusing surface, its solid angle increases, effectively increasing the beam angle. This effect cannot be reversed with linear passive optical components like reflectors or lenses.

Having a single LES as small as possible is therefore essential for good beam shape control. Two different color temperature sources in a single LES enable white tunable products with a narrow beam spot design. Not only does the single LES simplify and enable narrow beam spot designs, it makes it possible to minimize existing, tunable white spotlight designs.

A reflector originally designed for a normal, non single LES, tunable spot, can support a narrow beam design using a smaller single source LES, or if the aim is to keep the same beam shape, the reflector design can be minimized, allowing for smaller spots. Other recent innovations like the Direct Mountable Chip LED already made smaller designs possible [4][5]. An additional benefit of the tunable COB product is the convenience of assembly for the fixture manufacturer. Although the Direct Mountable Chip LED has the added benefit of increased flexibility, they still need to be mounted on a PCB. With very small sources like the Direct Mountable Chip LED, it might bring complexity in manufacturing and might require special assembly lines. The tunable COB package can be mounted using commercially available COB holders, similar to other COB products. There is an additional set of cathodes and anodes to connect, but the alternative would be designing a multi-channel PCB to mount the individual Direct Mountable Chip LEDs on and would still require a pair of cathodes and anodes to enable it to be white-tunable.

Figure 8 shows a comparison between the projected beam of a COB and a Direct Mountable Chip LED tunable white, both with the same reflector. Without a diffuser (**Figure** 8: Bottom), the color mixing of the Direct Mountable Chip LED solution shows some color-shadows around the edges.

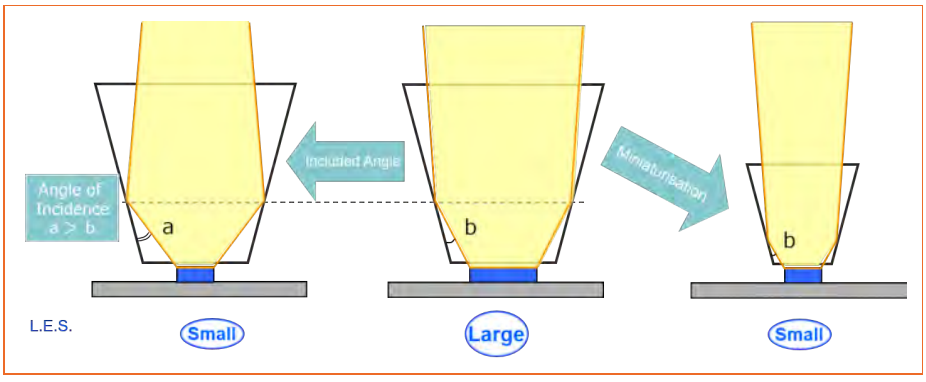

Figure 7: An example of how a spot design can be improved, or optimised for size.

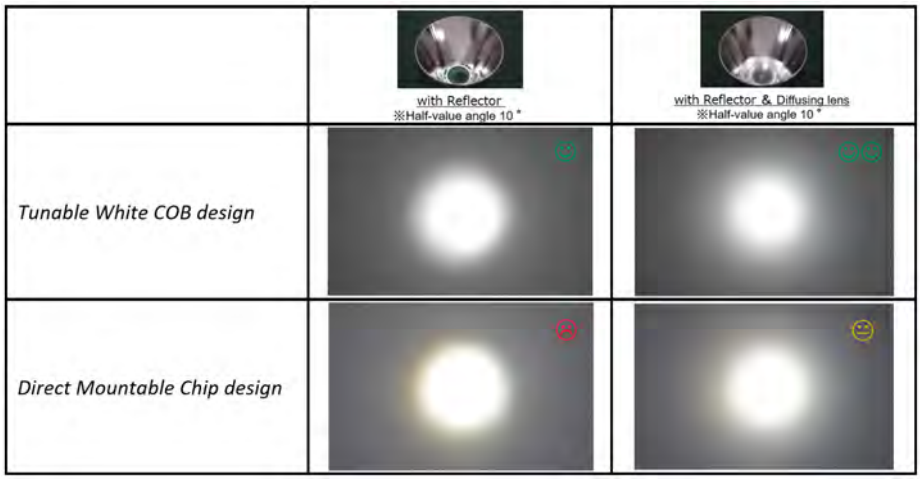

Figure 8: Comparison of projected beam of tunable White COB versus tunable Direct Mountable Chip solution.

The shadows become less when a diffuser is used, and in contrary leading to a more diffused projection.

The tunable white COB looks very similar to a Direct Mountable Chip LED tunable solution, but the COB has superior color mixing properties due to the internal diffusing top-layer resin (as illustrated in **Figure** 9) containing additional phosphor.

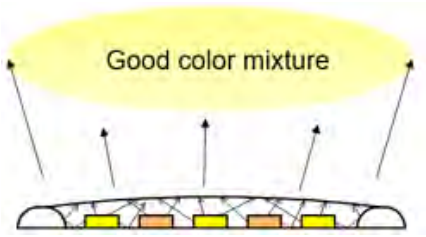

Figure 9: A schematic cross view of the tunable white COB illustrating the color mixture due to the top layer resin

Color Properties

The colorimetric properties of the light generated by a color tunable source are important. The intermediate colors are generated by a mixture of the light of the two 'primary' sources and only a color-point which is the result of a linear addition of the two primary sources can be generated. The intermediate colors are represented by a line between the two color-points in the 1931 CIE color diagram [2] as shown in **Figure** 10.

An ideal white tunable solution would have all its intermediate colors on the black body locus. The black body locus is, however, not a straight line in the 1931 CIE diagram, and the color gamut of the white tunable solutions is a straight line. There are very few points which perfectly match between the two, as a curved line and a straight line have at most two points in common. The further the color points of the two primary sources are apart, the larger the overall deviations from the black body locus.

A large color temperature range might seem attractive at first, giving the largest flexibility. Nevertheless, it would lead to larger deviations from the black body locus. A smart selection of color temperatures of the primary sources based on the application is crucial.

For office lighting, particularly in Europe, having 6500 K as one of the primary sources is not preferred. Having a cool white color temperature around 5000 K gives enough flexibility to implement the bright morning light. A color temperature of 2700 K in an office environment would also hardly ever be set as lighting color. With these limits on color temperature, a tunable white source having 5000 K and 3500 K as color temperature of the primary sources for office applications could be acceptable and still have a good match with the black body locus over the full tunable range.

A reduction of tunable range implies the need for a large variety of products offering different ranges of color temperatures depending on applications. As a compromise and as a market entry point, a single all-encompassing range (e.g. 2700 K–6500 K) is convenient and gives the lighting industry the opportunity to introduce this type of product, leading to feedback on desired color temperature ranges from different application fields.

Due to the proximity of the separate sources, the possibility of cross-talk between the sources should be considered. The implication of cross-talk in these products could be a reduced color range when compared to the individual sources. With only the cool white source emitting, some of the emitted light could unintentionally excite the red phosphor[4] leading to a warmer light than expected from just the cool white source.

The impact of the cross-talk will be different for different designs of a tunable product and should be verified on the final design of the product.

For this reason, the COB product has a cool-white color temperature of 5000 K and warm-white color temperature of 2700 K. The effect in the 2-in-1 mid-power product is much less and is therefore specified up to 6500 K while still maintaining a warm-white of 2700 K.

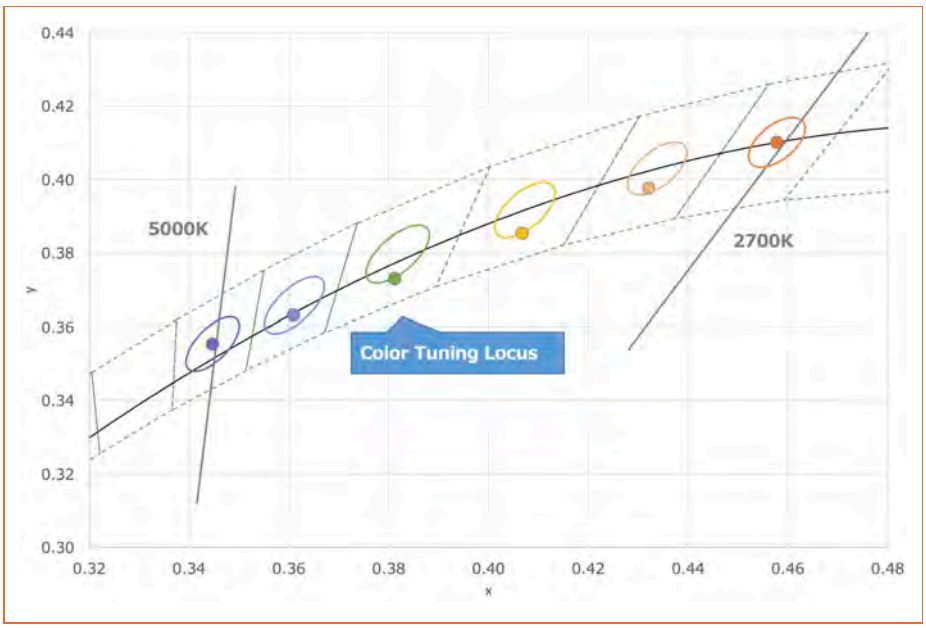

Figure 10: Color tuning locus of the tunable White COB.

Conclusion

HCL is relatively new but is being adopted by the lighting market at a high rate. This requires the lighting industry to develop innovations to keep up with the fast pace of adoption. Single LES tunable white solution is an innovation that enables improvement of existing lighting fixture designs, and also brings development possibilities of new tunable fixtures.

As an LED manufacturer, we must ensure reliability, optimum performances and better quality of light and continue to develop LED light sources based on phosphor conversion to answer current needs for reducing optical and electrical complexity, providing flexibility in design with more compact luminaires. ■

Figure 11: Nichia's 2-in1 Tunable White is available in LED 3030 Package and COBs. Also available in linear module LinearZ280-26 LED Strip 2-in-1 Tunable White from Lumitronix LED Technik GmbH

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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 worked as an optical measurement specialist at Philips Lighting and a British measurement laboratory earlier in his 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.

Figure 12: LpS 2019 - Sustainability Award for the "2-in-1" Technology

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Volume Manufacturing of Mini and Micro LEDs

Ever since since LEDs became a serious light source, ideas about further miniaturization has been in the minds of forward-thinking engineers and entrepreneurs. These ideas have become reality in the form of mini-LEDs and micro-LEDs. While opinions on how to use them and which applications they could be beneficial for, is clear, it is not quite clear what makes them different from conventional LEDs and what the challenges for manufacturers are. Sean Kupcow, senior R&D Engineer at Rohinni, talks about the problems in detail and proposes disruptive solutions that address these difficulties.

The display backlight and direct-emission display vertical markets have exhibited a growing demand for mini and micro LED solutions. The microscopic nature of these components introduces new challenges that have created barriers for widespread manufacturability and adoption in those markets. Addressing these challenges requires a reliable solution that places components at high speeds with accuracy and repeatability, contributing to unprecedented manufacturing yield.

When considering large scale production using mini and micro LED sized components, reliable placement at manufacturing capable speeds have prevented LED based direct emission devices from being economically viable when compared to backlit LCD and OLED display solutions that are currently available. This introduced the requirement for a sophisticated high-speed robotic placement system and a refined end-to-end manufacturing process to bridge the gap between a concept and a production ready solution.

Early on the path to the patented technology, it became clear that a strong relationship with LED chip manufacturers was essential. This deep ecosystem relationship allowed for an iterative design cycle and the procurement of bare die materials in compliance with process requirements. In addition, industry partnerships with strong expertise to properly address each product application regarding design, performance, high volume manufacturing, and distribution greatly accelerated the ability to address the growing market demand in volume. Finally, an inline automated rework system was developed that further solidifies high-yielding product manufacturing.

This article will discuss in greater detail the current industry problems facing micro and mini LED technology, as well as the disruptive solutions that address these problems and make widespread adoption of mini and micro LEDs a reality.

Introduction

Mini and micro LEDs have been referred to as the next generation of display technology for the last few years. Although many industry leaders have unveiled their own video wall displays and smaller-scale televisions with micro LED technology, nothing has entered mass production or even come close to reaching the average consumer. Key technological roadblocks needed to be addressed before mini and micro LED technology could be adopted by the broader semiconductor industry. Addressing these roadblocks will allow for the mass production and adoption of the new technology.

Process Overview

Mini LED technology includes die larger than 100 microns (µm) and up to 1 millimeter (mm). Micro LED technology includes die under 100µm (about one-tenth the width of a human hair), with spacing between the die as little as 10µm.

Figure 1 gives a visual representation of micro LEDs' tiny size.

These microscopic mini and micro LED die require a process faster than traditional pick-and-place processes to deliver speed and accuracy levels that will allow for their commercial viability. One solution, summarized in this article, involves individual components that are selected from a source and placed with a high degree of accuracy onto a substrate with a programmable product specific layout. Suitable for mini and micro LEDs, this process can place other small components as well.

Traditional pick-and-place solutions reach limitations when it comes to microscopic components and high rates of placement. It is necessary to address these challenges by designing the process to maximize placement speed and accuracy, remove the dependency on vacuum nozzle size limitations, and eliminate motion inefficiencies by bringing the LED source material to the substrate working area. This can be described as an "align and place" methodology, resulting in reduced transit time and increase placement rates.

The process begins with a bare circuit and bare LED components.
Custom/semi-custom die are sourced from top LED manufacturers and qualified with the placement process. The bare die used eliminate the bond wires and have the die pads on the bottom side. The die spec

requirements are highly application-specific, as well as design- and cost tradeoff-specific. An automotive tail lamp application, for example, would require an automotive-grade LED to withstand the stringent qualification requirements, while a very high-end display might use a die shape and bin with all the same wavelength to achieve best-in-class uniformity and brightness. Since the die on a single wafer can have many different wavelengths, the ability to eliminate the front-end wafer binning process by choosing the die bin and placing the die directly onto the product substrate is a huge advantage in terms of process time and cost.

Once the die and LEDs have been selected, a paste is applied to the pads on the circuit and inspected. The pasted circuit is then presented to the placement machine, which adjusts for circuit scaling and rotation. LEDs are identified on the source, aligned, and dynamically placed on the pasted substrate. After all die have been placed, the circuit is inspected and reflowed. Tight control on all processes surrounding the placement robot is required to ensure acceptable post-reflow yields.

Achieving High Speed and Accuracy

Understanding the size and spacing of LEDs on a display helps highlight how critical placement speed and accuracy are to manufacturability. The number of die used to create a display utilizing mini and micro LED technology raises the bar for required manufacturing yield.

Figure 1: At less than 100 microns in size, each micro LED is smaller than a human hair – about 1/10th the width

The first key roadblock that any solution must address is the development of placement technology allowing for six-sigma yield – generally required for commercial viability. Product application specifications require levels of placement speed, accuracy and process yield that reflect the economic viability of a product, not just manufacturability. The current technology allows for placement speeds of 50–100 LEDs per second (depending on application), with a roadmap aimed at reaching 1,000+ LEDs per second in the future.

In addition to the obvious requirement of an extremely accurate and repeatable placement robot, a high-end vision system is also critical. This allows for real-time die imaging and detection, as well as full-wafer "virtual binning" capabilities. Up-front processing of LED wafers into bin classes is no longer a requirement, which removes the need for costly material processing on the front end. The wafer map from probing/testing each die after the wafer is manufactured is used by the placement robot to determine where on the product each LED should be placed. There is immense value in eliminating this upstream process step while maintaining a high rate of placement.

Defect Management, Testing, and Repair

Reducing the number of failure points is one of the contributors to perfecting this manufacturing process. Using unpackaged die is an advantage, as it reduces failure points to the two die pads, anode and cathode, contacting the circuit pads.

Packaged LEDs have several more contact points with wire bonded connections that introduce areas of potential failure. These additional packaging steps add failure risk and significant cost compared to the use of bare LED chips.

Considering the market will demand products requiring placement of millions of microscopic LEDs at high speeds, even with an industry leading six-sigma manufacturing yield (meaning 1 out of 100,000 die can fail), defects are inevitable. Defect detection, management, testing, and repair are critical within the end-to-end process to maintain production viability. These processes involve identifying a failed location, removing material at the defect location both pre- and post-reflow, reconditioning pads when necessary, and replacing die. Post-reflow validation of the production process includes reliability and environmental testing that proves die bond strength is up to industry mil spec standards.

Communicating Design Flexibility and Value Proposition

To gain commercial traction and generate demand for the technology, eventually translating into economic viability, the value proposition of using micro LEDs must be clearly communicated. Many customers have yet to understand the vast product applications and flexibility that micro LED technology promises to deliver. Micro LED backlights outperform other solutions in a range of parameters, including cost, thickness, contrast ratio and brightness.

Inthe latter case, micro LED typically delivers 6000+ nits vs. 750 nits for edge-lit LCD, 1000 nits for OLED and 2000 nits for LED arrays.

Beyond the clear competition with OLED technology, micro LED backlights offer multiple substrate options including PET, polyimide (FPC), rigid FR4 PCB, glass and fabric. These substrate options offer product designers freedom to illuminate their creations in unique ways. In addition, as each microscopic die is individually electrically addressed, this process provides the ability to animate logos and indicators – Introducing light with motion, flexibility, and a range of colors (red/green/blue, or RGB).

With the micro LED approach described here, every application and performance requirement is customized based on design, performance and cost tradeoffs. Custom-made development samples were fully evaluated, based on the application demands, by joint venture (JV) companies (see "Go to market strategy" below). The JVs utilized the data to evaluate the technology and prepare a full A-to-B comparison against current market solutions using OLEDs or packaged LEDs. The approach can be thought of as a "toolbox" of options, with various LED die, substrates, conductive inks, drivers, etc. available to choose for a specific application – and a quality, high-volume manufacturing solution in place for all of the various options.

For example, PC OEMs require a low-cost consumer solution, so there is a toolbox option using a clear PET film, whereas a different option is needed for a high-end

Figure 2: Traditional packaged LEDs (left) are connected at multiple points, while direct-placed mini/micro LEDs (right), with only two points of connection, are much less prone to failure

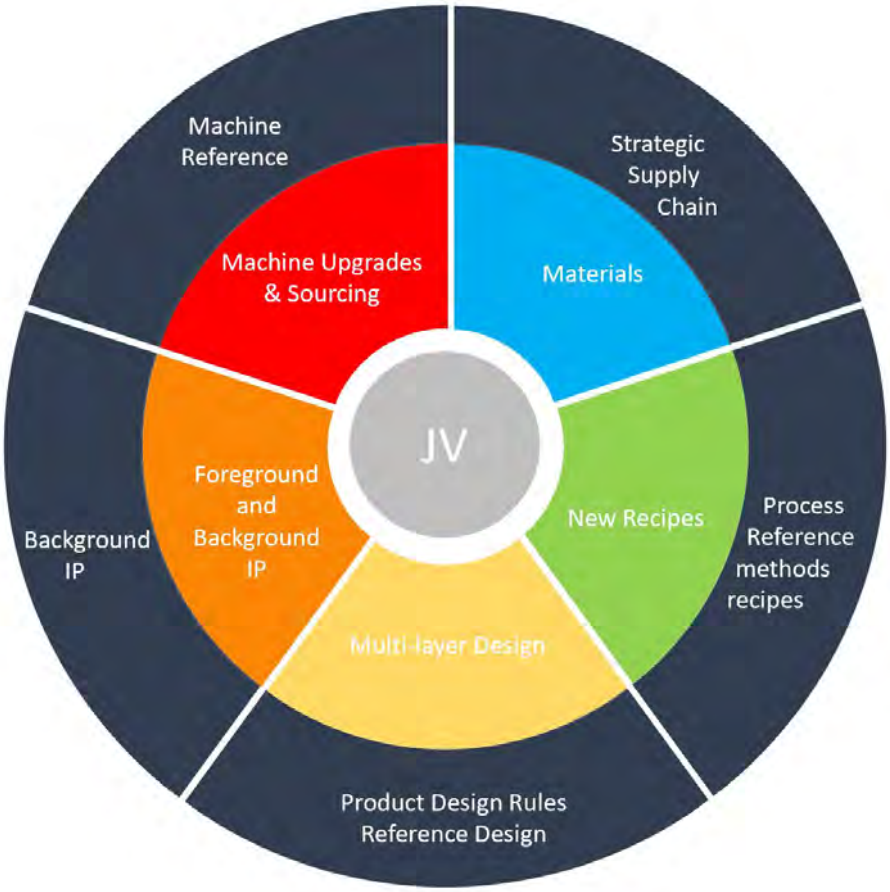

Figure 3: The JV universe, or ecosystem, unites a variety of capabilities and assets contributed by both venture partners to create a best-of-both-worlds scenario for getting end products to market

display, which requires best-in-class brightness and zone dimming. In this case, an FR4 circuit is used to individually address each LED, and the highest-performing LED die is selected for use from the toolbox.

Micro LED technology offers a much more energy-efficient solution for lighting with lower power consumption and a longer lifetime due to the very low constant current needed to drive each LED. At this lower driving current, the die reach peak efficiency and provide optimal performance with reduced thermal levels. These benefits are possible through a process that uses industry-standard building blocks and allows for product flexibility desired by the market.

High-Volume Supply Chain and Materials

Circuit/substrate materials

Control of incoming materials is one of the most critical aspects of the mini and micro LED production process. When dealing with microscopic components, the dimensional tolerance of input material is key to achieving a desirable post-reflow yield.

Substrate materials like glass and rigid FR4 can hold tight manufacturing tolerances and are generally easier to produce without much process adaptation. When introducing flexible circuit designs with PET, FPC, and fabric, the tolerances become much wider due to the nature of these materials. There is great benefit in collaborating with material suppliers to generate a product that is manufacturable in high volumes. Simply creating a specification – one that may be too tight for the production of circuit materials to be financially viable – doesn't work. The result would be extremely high substrate costs due to waste from failed material construction. Alternatively, simply accepting materials that are too far outside of a reasonable specification would result in failures on the product identified at the end of the process.

Focusing on production specifications that are critical to quality allows the manufacturer to improve production yields, and the process provider adapted the paste and placement processes to adjust for dimensional inconsistencies. The result of the collaborative effort is a synergistic relationship focused on high-volume production of substrate materials, allowing for economically feasible mass production.

LED Materials

The ability to acquire raw LED chips from the manufacturer presented on the desired material with a wafer map indicating test results from die probing is critical to this direct-placement process. This allows for "virtual binning", as previously described, and increases the value proposition by reducing material handling costs. This means that the LED manufacturer can eliminate the slow, costly step of physically sorting the die.

By reducing manufacturing burden and overhead, LED manufacturers can provide a high volume of LEDs more quickly. The upstream process of die sorting is pushed downstream to the manufacturing of

products, but with a greatly reduced cost due to the new placement process, allowing for virtual binning and high rate of placement.

Get-to-Market Strategy

Startups with a new technology are often faced with deciding how best to get to market with their invention. In this case, for micro LED process technology, there are three identifiable revenue generators:

- The high-speed robotic placement equipment production and sales
- Unique manufacturing process know-how
- Final product-application offerings

A firm must decide which opportunity to focus on and pursue. Typically, the path of least resistance is to simply license the robotic placement technology; however, it is usually the least profitable and at times the least successful due to the licensee not having the ability to produce and distribute the highly complex technologies in volume.

The next option is to raise a large amount of capital and to invest in building a manufacturing facility for the high-speed placement equipment, as well as the finished product application. This path is high-risk due to the enormous infrastructure that needs to be developed and supported, but it also has the potential for the highest return on investment if successful.

Rohinni's decision was to choose the path that provided the best of both worlds by including revenue from all three value generators. This path is best pursued in forming JVs with partners in specific vertical markets. These partners have well-established quality, high-volume production facilities, product-application expertise, and existing sales and distribution channels. Paired with the robotic equipment sales and production, manufacturing process know-how and product application offering, this path capitalizes on the work done by the startup (in this case, Rohinni) and all potential revenue sources. In addition, it significantly reduces the overall risk, provides built in economical motivation to ensure both partners are successful, and combines the best attributes of each partner – one a fast-moving creative startup, the other a large, disciplined industry expert. **Figure** 3 illustrates the JV ecosystem.

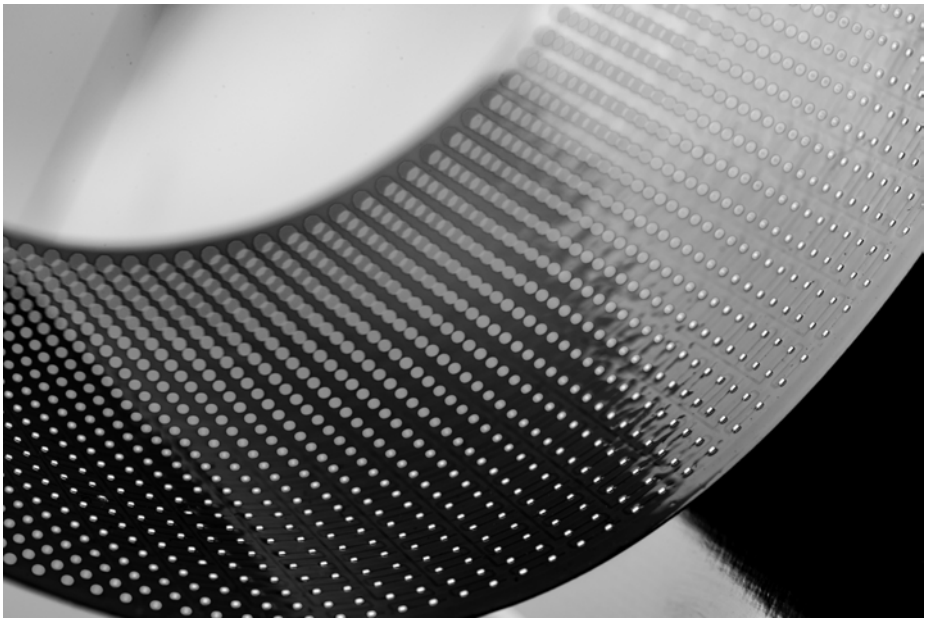

Figure 4: Micro LEDs placed on a circuit

Conclusion

Given all of the aforementioned process roadblocks and a complex market, a complete solution is required to bring micro LED technology to consumers. A truly disruptive process would include a high-speed placement robotic system to place the micro LED die quickly and accurately. An entirely new manufacturing process is required that offers an end-to-end product solution. Micro LED technology cannot simply be an addition to an existing process but will require an entirely new process.

With suppliers also recognizing the vision to disrupt the current industry standards, LED manufacturers are providing bare LEDs in RGB colors, circuit substrates are being developed to support these micro LEDs, conductive ink suppliers are working to support the placement process window, and intelligent automated optical inspection (AOI) and measurement systems are being employed. All are working together to ensure a high yielding process. ■

ABOUT THE AUTHOR

Sean Kupcow: Sean, Senior R&D Engineer at Rohinni, is an experienced development engineer and has spent the past four years at Rohinni in various roles. He was one of the inventors on more than 15 patents granted to the Rohinni team highlighting technology that enables the commercial use of mini and micro LEDs, and has been a part of the Rohinni team that developed the industry's fastest and most accurate mini and micro LED placement technology. Before joining the Rohinni team, Sean worked as a team manager and software implementation consultant at Fast Enterprises. Sean graduated from the University of Idaho in 2011 with a B.S. in Marketing and Information Systems.

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FF-MOEs — The Potential of Tailor-made Light-directing Structures on Film for Enabling New Design Possibilities for Luminaires

Recent research has shown that free-form (FF) optics can uniquely generate tailor-made radiation patterns or irradiance distributions in a very efficient way while the fabrication of such optics is challenging and costly. The presenter and the authors of the shortlisted paper for the Scientific Award 2019, Dr. Claude Leiner, DI Wolfgang Nemitz, Dr. Ladislav Kuna and Dr. Christian Sommer from Joanneum Research, proposed utilizing the potential of roll-to-roll UV nanoimprinting technology based freeform micro-optical elements (FF-MOEs) on film to master this challenge.

Research in recent years has shown that free-form (FF) optics offers optical designers new possibilities in many different areas, as it can uniquely generate tailor-made radiation patterns or irradiance distributions in a target area in a very efficient way that cannot be achieved with conventional optics. On the other hand, the fabrication of such optics is challenging in many cases, which can result in high manufacturing costs.Limiting the maximum height of the FF optics is a promising approach in this context as it promises new design possibilities for luminaires and allows a more cost-efficient production with a high throughput e.g. using roll-to-roll UV nanoimprinting technology. A wall-wash applicaton where an LED light source located on the ceiling of a room that should homogenously illuminate an adjacent wall is an intersting example for testing the optical capabilities of such an approach because it requires a strong light direction to produce an asymmetric radiation pattern, and therefore has high demands on the optical system. In this context, we present the potential of free form micro-optical elements (FF-MOEs) on film to meet these requirements.

Introduction

Light emitting diodes (LEDs) are the most commonly used light sources today and surround us almost everywhere in our daily lives, be it in luminaires for room lighting, street lighting or as background lighting in almost all displays. The reason for this is the multitude of advantages of LEDs as light sources, including their long-life, energy-saving aspects, their simple system integration and their availability in different sizes.

The different sizes especially promote the development of so-called freeform (FF) optics, which are usually calculated under the approximation of a zero etendue light source, i.e. a point light source or a parallel beam, and therefore require light sources with the smallest possible light-emitting areas. In order to mitigate unwanted effects caused by the lateral dimension of the light source an adequate distance between the light source and the FF-optics is needed to reach the approximation of a point-like source. However, by increasing the distance between the light source and the optics, the lateral expansion of the optics is also increased in order to keep its functionality.

This type of FF-optics are very challenging for production and replication because of the non-symmetric shape of the optical surface. Techniques like diamond turning, milling, grinding and polishing are used in general for manufacturing the required metal molds for injection molding, the most common technique used for the replication. The throughput of an injection molding machine depends on the overall cycle time of a single mold, where typically 50% of the cycle time is used for cooling the mold. In the equation to calculate the minimum cooling time for a plate [1], the thickness of the plate is entered as a square value, resulting in lower throughputs for thicker FF-lenses.

In our earlier work [2], we presented a smart design method for so-called freeform micro-optical elements (FF-MOEs), which have similar optical properties to conventional voluminous FF-optics, but with adjustable height of the structures. Byincluding thresholds values for the height into the calculation algorithm directly, the calculated FF-MOEs can be restricted to a very flat design (e.g. a maximum of 50 µm or 75 µm), which is also favorable for the throughput of injection molding and even enables alternative production techniques for mastering [3] and replication [3], [4].

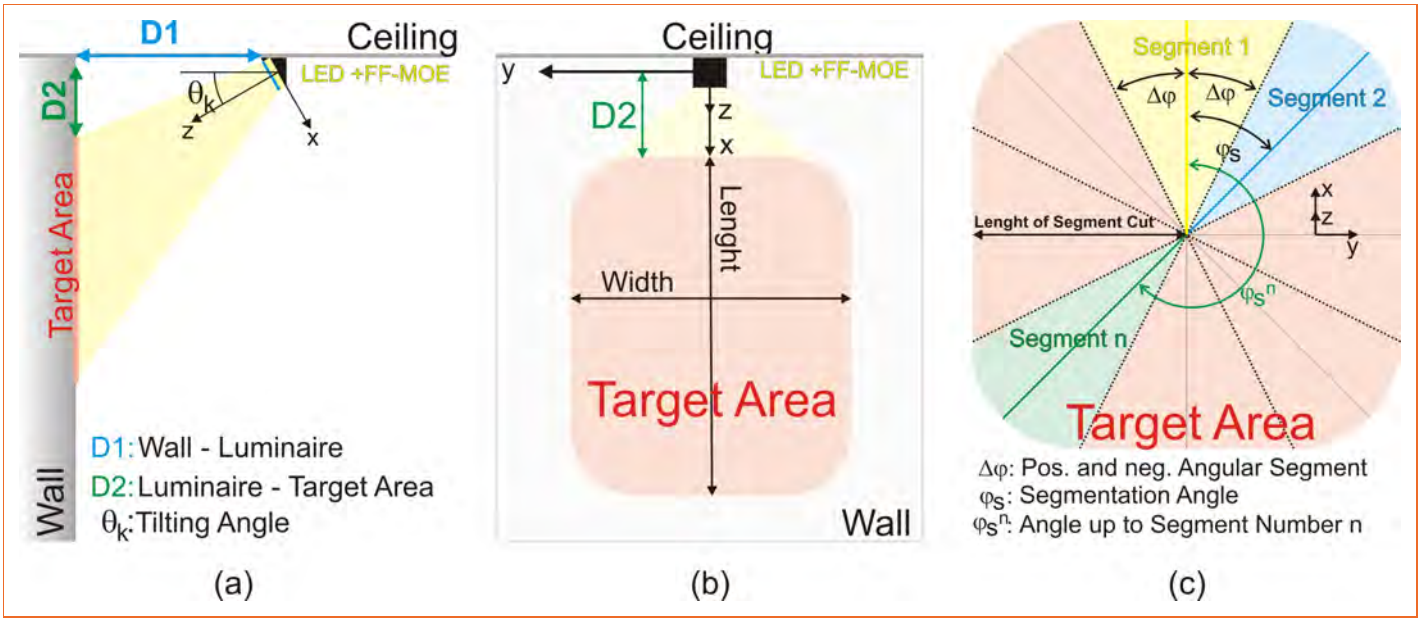

Figure 1: a) Experimental setup to align the structure of the FF-MOE with the light source. b) Demonstrator unit of the wall-wash luminaire, placed on an angle adjustable support. c) Simulated irradiance distribution on the wall for a qualitative comparison with the experimental results. d) Camera image of the transmitted irradiance distribution generated by the demonstrator unit on the projection surface

In [3] we discussed an approach for the cost-efficient fabrication of suchlike FF-MOE structures by a mastering method based on an in-house build experimental system for mask-less laser direct write lithography (MALA-System) and a replication of the master structures by UV-nanoimprint lithography (UV-NIL). The MALA system is using a 'virtual' photomask, which specifies the respective light dosage at a given lateral XY-position of the FF-MOEs and which is directly generated from the 3D model. As a result, the fabricated FF-MOEs showed high quality in terms of shape fidelity and optically glad surfaces.

Due to the flat design of the FF-MOEs even large scale reproduction methods like e.g. a roll-to-roll (R2R) UV-NIL process can be used [4], capable of manufacturing high quality FF-MOEs on films with an imprinting speed of 1 m/min [4]. Especially for applications where the optical system consists of an array of light sources or for applications where the optical elements have large areas, the R2R-UV-NIL process has already become a mature technology for the cost- and time-saving production of optical elements.

As mentioned above, the calculated FF-MOEs can have a similar optical functionality as conventional voluminous FF optics and can generate a defined radiation intensity or a defined irradiance distribution in a target area. In [5] we presented an alternative optical system using FF-MOEs for a direct-lit luminaire, where an array of LED light sources is generating a homogeneous irradiance distribution on the exit surface of the luminaire. Key parameters of a similar luminaire are the homogeneity of the irradiance distribution, a low height of the luminaire for design reasons as well as a high DHR ratio, which is the ratio of the distance between the LED light sources of the array and the height of the luminaire. By using FF-MOEs on films, the DHR value can be significantly increased (by a factor of 3) with comparable homogeneity of irradiance distribution. Furthermore, the flat design of the FF-MOEs allows a thin design of the luminaire [5].

In this contribution we will discuss the use of FF-MOEs for the realization of a wall-wash (WW) luminaire.

Design and Simulation of the FF-MOE

A schematic representation of the wall-wash set-up is shown in **Figure** 1. In order to determine the surface illuminated by the experimental demonstrator in a much defined way, the setup was downsized by a factor of ten compared to the practical applications of WW-luminaires.

However, the width and the height of target area are directly scalable with the distance D1 from the light source to the wall, so that the investigated properties of the FF-MOE regarding light management and homogeneity of the generated irradiance distribution are correlated with larger optical systems. The parameters of the optical system, the light source and the FF structure were assumed with the following values:

The active area of the LED light source was assumed to be square with a side length of 0.5 mm. The imprinted structure of the FF-MOE with a refractive index of $n = 1.52$ is located on the side of a 1 mm thick PMMA substrate ($n = 1.49$) directed away from the light source. The bottom of the substrate was positioned at a distance of 1.5 mm from the light source. The target area has an oval shape with a width of 200 mm and a height of 280 mm.

The distance D2 from the light source to the target area was set to be 0 mm, the distance D1 from the light source to the wall 125 mm. Due to the 2-dimensional approximation of the FF algorithm, only the polar angle but not the azimuth angle of the rays can be changed by the FF-MOE.

For this reason, the light source is positioned in a way that the optical axis lies in the centre of the target area (**Figure** 1) and is tilted by a suitable angle k = 48.24 to the surface normal of the wall.

The calculation of the FF-curves of the FF-MOEs for the wall-wash applications is essentially similar to the procedure described in [2] and [5], but differs in the calculation of the ray-mapping step because the target distribution in this system is asymmetrical to the optical axis of the illumination system. The given radiant intensity distribution of the source IS(θ) has to be modified by the FF-MOE into a radiant intensity distribution IL(θ), which generates the desired irradiance distribution onto the target plane. In order to calculate the FF-curves of the FF-MOE, the modified radiant intensity distribution IL(θ) is

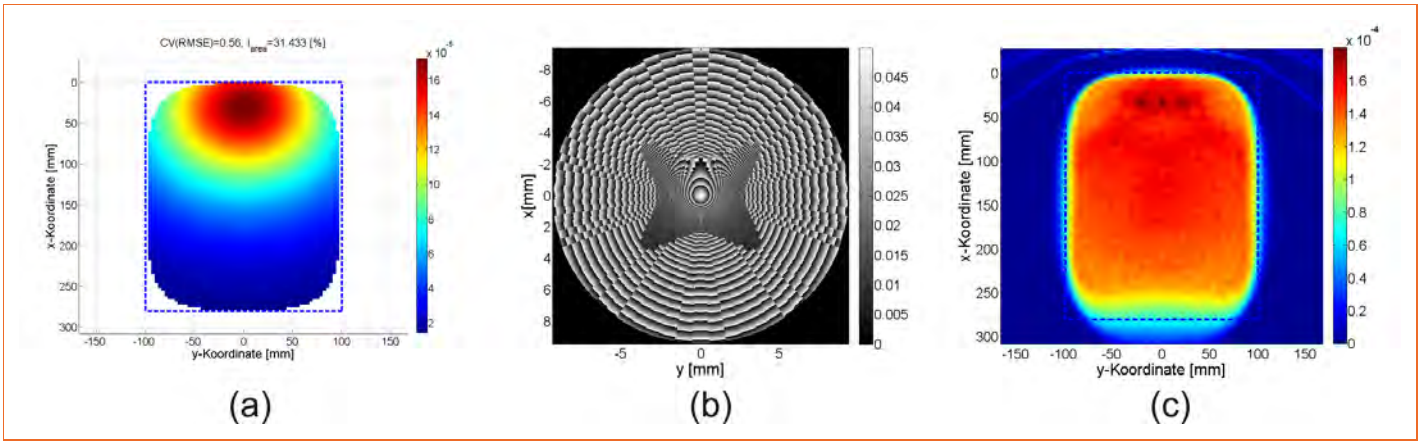

Figure 2: a) Simulated irradiance distribution within the oval shaped target area without FF-MOE. b) Calculated structure of the FF-MOE with a maximal height of 50um. c) Simulated irradiance distribution within the oval shaped target area with FF-MOE

projected onto the target plane to define points R^i on the target plane, which have to be hit by the rays i, transmitted through the FF-MOE, to generate the desired irradiance distribution onto the target plane. The distribution of the points R^i within the target area is invariant to a translation or rotation of the target area in space. This allows a ray-mapping of the target area in a rotationally symmetric position with respect to the optical axis of the system and subsequent use of suitable rotation and translation operators to position the target area on the wall.

As described in [2], non-radial target distributions are realized by segmenting the shape of the target distribution (**Figure** 1c). The FF algorithm calculates independent FF curves for the different segmentation sections. The segmentation angle φ_S can, in principle, be freely selected, and determines the number of segments N required to illuminate the entire target area, as well as the radial size of the individual angle segments.

The calculated FF curves are then extruded radially and stitched together. As already discussed in [2] an adequate number of segmentations ensure a satisfying stability of the desired shape of the distribution.

To evaluate the optical functionality of the calculated FF-MOE, optical simulations were conducted using a commercially available simulation software for ray-tracing (ASAP — Breault Research Organization), where both the incident light intensity and the homogeneity of the irradiance distribution within the target area were evaluated. In order to assess and compare the homogeneity of the intensity distribution, the coefficient of the mean square deviation (in terms of CV(RMSE) value) was calculated [5]. In this definition of homogeneity, a smaller value represents a higher degree of homogeneity.

Figure 2 a shows the simulated irradiance distribution within the oval target area on the wall without using the FF-MOE, simulated with 20 million rays. In this configuration, 71% of the light emitted by the light source hits the entire wall, while only 31.4% of the intensity is within the oval target area. The irradiance distribution within the target area also has a high CV(RMSE) value of 0.56.

Figure 2b shows the structure of the final FF-MOE consisting of 80 segments with a maximal height of 50 µm. As can be seen, the structures in the center of the FF-MOE became asymmetrical, taking into account the asymmetry of the target area with respect to the optical axis of the system.

Figure 2c shows the simulated intensity distribution within the oval target area on the wall, simulated with 20 million rays. The FF-MOE now directs 62.5% of the light emitted by the light source into the target area and distributes it comparatively homogeneously within the target area, so that a CV(RMSE) value of 0.124 could be achieved. Additional tolerance simulations have shown that the lateral expansion of the light source is causing a “smearing” of the light-dark boundary of the intensity distribution especially in the lower area of the target distribution (**Figure** 2c x values in the range of 250–280 mm) leading to higher CV(RMSE) values and to a lower intensity within the target area.

Experimental

Figure 3a shows a 3D model of the simulated FF-MOE. Similar to [3] the MALA-System was used for manufacturing the master structures for the FF-MOE. For an efficient and successful production of the master, it is necessary to know the modulation of the microstructure depth (minimum-maximum), the detailed shape of the individual parts of the FF-MOE, the size of the active surface and the surface quality requirements. Since FF-MOE consists of a relatively complicated asymmetric structure with steep flanks of the individual facets and a target height of 50 µm, an optical 4× microscope objective with a numerical aperture of 0.16 as focusing optics was selected for the laser writing. On the one hand, the depth of field of the objective of ~ 110 µm allows producing the deeper microstructures (> 40 µm), on the other hand, the lateral resolution of 2.5 µm allows a sufficient description of the finer forms of the FF-MOE. From this model analysis a lateral scanning resolution of the laser lithography of 1 µm in X- and Y-direction was determined. The substrate consisted of a 2 inch silicon Si) wafer on which a positive tone photoresist was applied over two spin-coating runs to achieve a total layer thickness of approx. 65 µm. In order to determine the optimum process parameters for laser writing, individual series with test structures (trenches) were written into the sample. Laser power and writing speed were varied for each structure of the series. The final microstructures were generated after the laser writing by wet chemical development. In order to avoid the risk of destruction of the microstructure due to overexposure, the multiple exposure strategy was used. As a result of the test, it was determined that the sample should be scanned three times with the focusing laser beam. Thus, the effective duration of the laser structuring for the production of a master is about 18 hours. This production time results from the complexity of the microstructure, the surface quality requirements and the shape accuracy of the microstructure. **Figure** 3b shows a light optical microscopic image of a successfully fabricated master with FF-MOE structure. Finally, the master was molded with PDMS to form a stamp for further processing. Subsequently, an UV curable Urethane Acrylate (UA) imprint resin was deposited

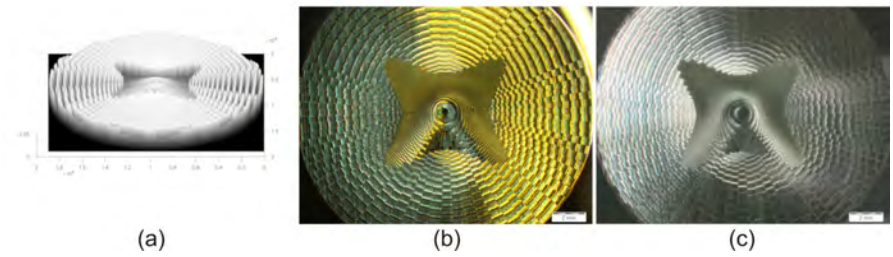

Figure 3: a) 3D Model of the calculated FF-MOE. b) Light optical microscope images of the master structuresof the calculated FF-MOE, manufactured using the MALA-System. c) Light optical microscope images ofimprinted FF-MOE structures on a PMMA substrate

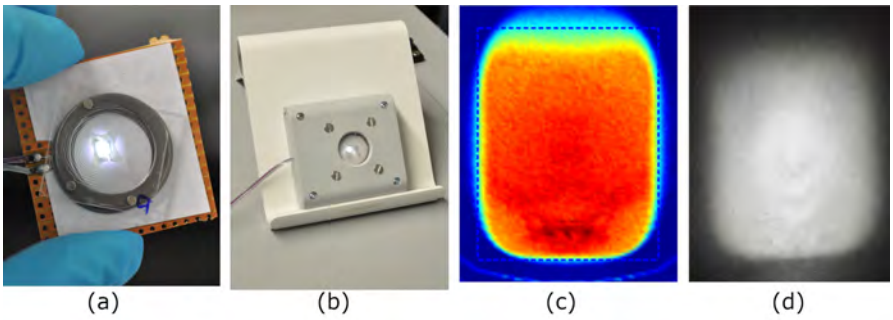

Figure 4: a) Experimental setup to align the structure of the FF-MOE with the light source. b) Demonstrator unit of the wall-wash luminaire, placed on an angle adjustable support. c) Simulated irradiance distribution on the wall for a qualitative comparison with the experimental results. d) Camera image of the transmitted irradiance distribution generated by the demonstrator unit on the projection surface

onto a PMMA substrate and the microstructure of the FF-MOE was imprinted using the PDMS mold. The UA was cured by UV irradiation through the PDMS stamp. **Figure** 3c shows a light optical microscopic image of the imprinted FF-MOE on the PMMA substrate.

A white light LED with an area of $0.5 \times 0.5\,mm^2$ was used to experimentally evaluate the FF-MOE. The distance between the bottom of the substrate with the FF-MOE and the LED was adjusted using spacer elements. The substrate of FF-MOE was fixed to these spacer elements (**Figure** 4a). The aligned FF-MOE was fixed inside a demonstrator housing for the wall-wash luminaire and placed on an angle adjustable support. For this setup a sheet of paper was fixed onto a plexiglass panel perpendicular to the tabletop, so that the irradiance distribution on the surface could be taken in transmission, in order to avoid a shading of the irradiance distribution by the optical system in the camera image.

Figure 4d shows a photo of the transmitted irradiance distribution, generated by the demonstrator. A qualitative comparison with **Figure** 4c, the simulated irradiance distribution of the FF-MOE on the target wall flipped by 180 degrees, shows a very good result as regards the form and homogeneity of the generated irradiance distribution.

Conclusion

In this contribution the potential and advantages of ultrathin freeform micro optical elements, so called FF-MOEs, were discussed and demonstrated according to the task of a wall-wash application.

It was shown that by adjusting the ray-mapping the algorithm for the calculation of the FF-MOEs could be adapted so that a suitable FF-MOE with a maximum construction height of 50 µm could be calculated which distributes the light emitted by the light source homogeneously into an oval target area on an opposite wall. A raytracing simulation of the functionality of the FF-MOE highlighted that the intensity within the target area could be increased from 31.4% to 62.5% with a simultaneous reduction of the CV(RMSE) value from 0.56 to 0.124, which represents a considerable increase of intensity and the homogeneity of the irradiance distribution within the target area.

By applying the technique of the mask-less laser direct write lithography master the complex asymmetric structures of the calculated FF-MOE were fabricated, molded with PDMS to form a stamp and sub sequentially UV-imprinted on a PMMA substrate using the PDMS mold. A demonstrator for the wall-wash luminaire was realized and used in order to experimentally evaluate the optical functionality of the FF-MOE. A qualitative comparison between the experimental and the simulation results shows a very good result as regards the form and homogeneity of the generated irradiance distribution. The presented innovative approach opens the door not only for new applications in the field of LED based lighting systems, but also for the time and cost effective fabrication of complex micro-optical components on films. ■

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3D Printing: New Disruptive Fabrication Technologies for a Novel Design Approach

Some manufacturing technologies and tools that were only used in pre-production or prototyping for a long time have become state-of-the-art for mass production. 3D printing is one such technology. Lighting designer, Ruairí O'Brien, stated that, in his opinion, this could be a risk for the business of traditional luminary manufacturers if they don't adapt. In response, we asked the specialists in this field, Claudio Pucci, designer, and Eng.D. Enrico Cozzoni (PhD), senior scientist and aerospace engineer at Grado Zero Espace to write an article to explain what state-of-the-art really is, what is possible, where the current limits are, and what the prospects are.

Rapid production, and its different forms, has been moving steadily toward a mainstream manufacturing technique. It is a disruptive technology that has the potential to affect a range of industries, introducing and extending the limitations of the actual Design & Production paradigm. In addition, it can easily produce customized and personalized objects, starting from any type of digital model, also and especially objects that were previously mere design concepts.

General Introduction to Rapid prototyping and Production

There has been ample research on rapid production in areas like materials and processes (Norton 2001), but previous studies have not paid sufficient attention to increasing the understanding of what the aspects beyond manufacturing are that need to be addressed in order to successfully adopt novel rapid production technologies. For instance, Bogue (2013) points out that 3D Printing technology is being used in a variety of applications, which basically fall into two broad categories: Rapid Prototyping and Component Manufacturing. While it is possible to consider rapid production as an effective transition in the product manufacturing, it is also fundamental to decompose it into five consecutive evolutionary steps that should be understood, to capitalize on the potential associated with rapid production technologies.

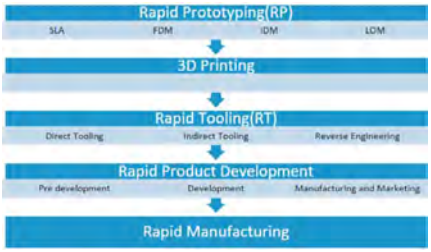

Figure 1: Evolutionary steps in Rapid Production (courtesy of Muita et Al. 2015)

We will examine three of these evolutionary steps.

Rapid Prototyping (RP)

The first domain we will introduce is that of Rapid Prototyping (RP), where this term is used to describe the process of rapidly creating a system or part representation before final release or commercialization (Gibson 2010). In product development, Rapid Prototyping refers to technologies that create physical prototypes from digital data simulations. Furthermore, it allows users to test prototypes of different versions of the models before full-scale manufacturing. Prototyping is an essential part of the product development and manufacturing cycle required for assessing the form, fit, and functionality of a design before a significant investment in tooling and production is made (Pham & Gault 1998). Rapid prototypes, i.e., goods derived from Rapid Prototyping, are mostly applied in design and development, product evaluation, production and process analysis, and manufacture tooling fabrication.

The application fields for Rapid Prototyping, that span from Electronics to Consumer Goods, are growing, overcoming the previous limited use of the technologies, mainly due to a gap in the quality, strength, and volume of the goods produced using the available Rapid Prototyping technologies. The main reason is that Rapid Prototyping processes have already shortened turnaround times and lowered costs, against a growing quality of the final product. These factors bring about significant time and cost savings in product testing and development, enhancing the competitive advantage of a firm.

Figure 2: Rapid Prototyping cycle

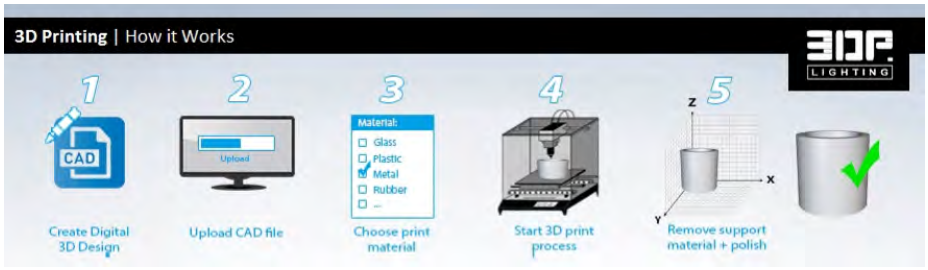

Figure 3: 3D Printing steps (courtesy of 3DP-Lighting)

Rapid Prototyping comprises several different processes that can be categorized into ten main categories (Labgraph 2014). Stereo lithography (SLA) is notably the most popular Rapid Prototyping process, because it is perfect for fit and form testing or show models. Selective Laser Sintering (SLS) and Selective Laser Melting (SLM), is a family of layer-wise material addition techniques that allows generating complex 3D parts by selectively consolidating successive layers of powder material on top of each other, using thermal energy supplied by a focused and computer-controlled laser beam. SLS and SLM are commonly used for prototyping and production applications. Fused Deposition Modeling (FDM), which works on an additive principle by laying down material in layers, is also commonly used for modeling, prototyping, and production applications. Inkjet Material Deposition (IDM) is an emerging technique in which inkjet technology is used to deposit materials on substrates. In Laminated Object Manufacturing (LOM), layers of adhesive-coated paper, plastic, or metal laminates are successively glued together and cut to shape with a knife or laser cutter.

3D Printing

3D Printing or Additive Manufacturing (AM) is used to convert a 3D model into a three-dimensional object through additive processes in which successive layers of material or droplets are laid down under artificial intelligence. The 3D Printing process is quite simple: in fact, 3D Printing is based on the idea of adding material: building up a product "layer-wise", or for precision manufacturing, such as printed optics, even with "droplets-on-demand". This method is used rather than starting with a solid block or sheet of material and then removing the material that you don't want, such as machining.

The material used for this purpose is called 3D printing material. 3D printers can use a wide range of materials, including plastics, resins, metals, ceramics and many more. Today, the most popular material is plastic, and most of the desktop style printers print objects using plastic. However, some of the higher-end printers are capable of printing using many different materials. Currently printers support over 100 different materials.

Using 3D Printing equipment today, you can already choose from a great variety of materials, those presented above, to create your objects, with many more new materials on the rise. Having a digital CAD file that specifies the exact shape contours and complexity of the product to be printed is only one step from the digital design process towards the real end product.

In contrast, current manufacturing processes use a subtractive approach that includes a combination of grinding, forging, bending, molding, cutting, welding, gluing, and assembling (CSC 2012). The use of 3D Printing in a variety of sectors is rapidly gaining momentum; for example, it provides a fast and cost-efficient means of fabricating parts of machinery and instruments with customized design (Bogue 2013). 3D Printing's rapid evolution can be attributed to mainly two features:

- Control of how the ingredients are deposited
- Its flexibility to manufacture different products, contrasting it to traditional manufacturing methods, in which the production line must be customized and tailored if the product line is changed, requiring expensive investment in tooling and long factory down-time (CSC 2012)

There are various machines that can be used in 3D Printing. The main difference between them is related to how the layers are built up. Unlike a laser that draws a single line to convert material, 3D printers leverage their raster scan print head architecture to increase the amount of converted material (Bak 2003). Each layer

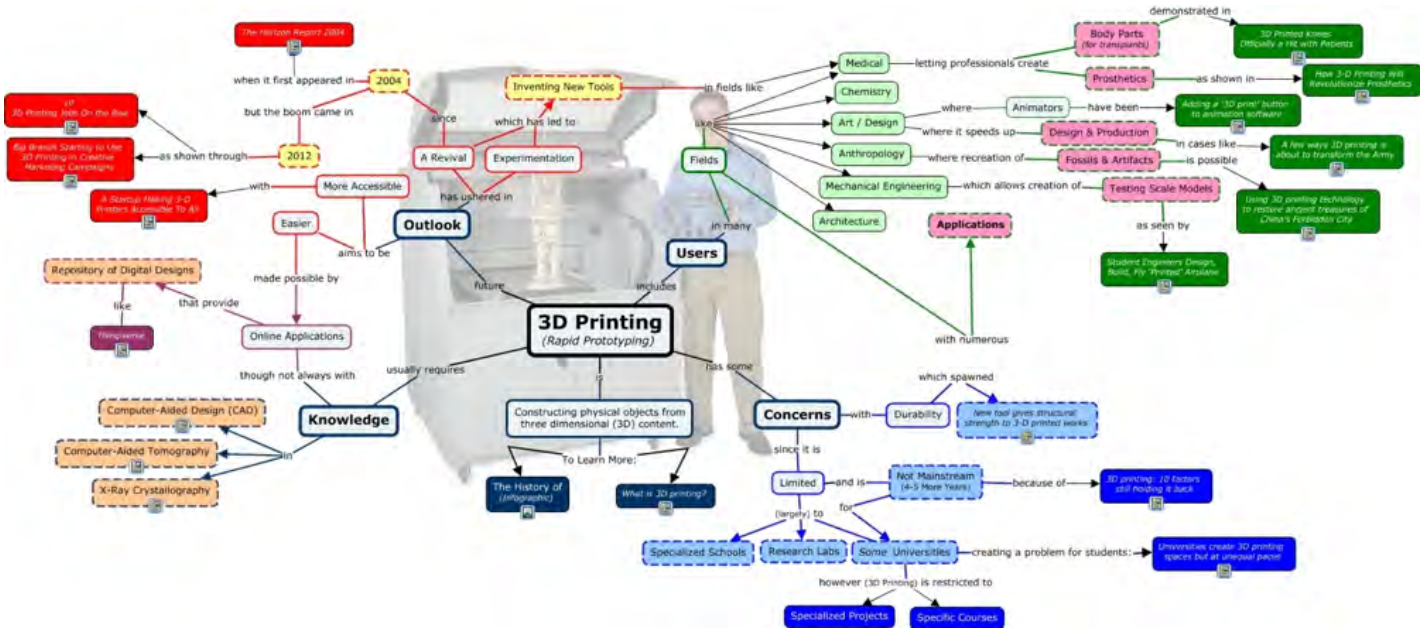

Figure 4: 3D Printing conceptual map

Figure 5: 3D Printing of metal housing for a pendant solution (courtesy of Grado Zero Espace, Repro-Light project)

Figure 6: 3D Printing one-piece heat sinks for lighting applications

is added until the object is fully printed or 'manufactured' with an extruder (fused filament), chemical agent (binder), or a laser (sintering/melting) changing the state of the material (Birtchnell & Urry 2013). In the manufacturing context, the technologies are particularly well suited to the production of components with complex geometries such as internal passageways, undercuts, and other features that are difficult or even impossible to manufacture with conventional techniques (Bogue 2013). Berman (2012) suggests there are two aspects that make 3D printing different from other rapid prototyping technologies:

- It enables small quantities of customized goods to be produced at relatively low costs
- It allows seamless integration with Computer Aided Designs (CAD) and other digital files like Magnetic Resonance Imaging (MRI)

In addition, 3D printing changes the logistics chains by providing a platform for local production instead of large-scale and centralized manufacturing. This enables collaboration that is accelerating innovation and disruption in the material world, just as the Internet fostered collaboration, innovation, and disruption in the digital world (CSC 2012).

Rapid Manufacturing

Rapid Manufacturing is the ultimate view of Rapid Production. It is commonly viewed as a new philosophy providing an industrial revolution for the digital age. Hence, genuine Rapid Manufacturing systems employ additive processes to deliver large masses of finished goods directly from digital data and effectively eliminating all tooling (Bak 2003). According to Labgraph (2014), the main processes that lead towards rapid manufacturing, in sequential order, are considered to include:

- **Product design** – it includes the product definition, material choice, Rapid Prototyping process selection, marketing evaluation, value-estimation, optimizing design, choosing packaging, and preparing the handbook.
- **Rapid product development** – it includes the rapid prototyping, rapid tooling, and prototype evaluation, small batch production in order to test standards, assembly definition, production cycle, and investment analysis.
- **Marketing** – it involves the formulation of market research that includes start-up plans, break-even analysis, advertising, pricing strategies, and strategic market approaches. International agreements

These are activities that involve the distribution of goods and access of outside markets to capabilities that will facilitate production and distribution of goods and services to target market.

Regarding the adoption and future possibilities of Rapid Manufacturing, Cloud-based Design and Manufacturing (CBM) provides interesting opportunities. It is a networked manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources (Dazhong et Al. 2014). It signifies the evolution of manufacturing and allows for optimal resource allocation in response to a customer's variable task. Moreover, it optimizes processes by forming temporary production lines, thus saving cost, increasing speed, and reducing turnaround time for clients. CBM combines many elements of new technologies, including cloud-based services, CAD, and rapid production.

In 3D Printing, additive processes are used, in which successive layers or droplets of a certain material are laid down under computer guidance. The printed objects can be of almost any shape or geometry, since in the most processes a removable supporting material is printed along with the structures. They are produced from a 3D model or other electronic data source.

3D Printing (also known as Additive Manufacturing, AM) is any of the various processes used to make 3D-objects. 3D Printing Lighting is a next revolution in the world of making, also referred to as the 'third industrial revolution'.

3D Printing – in the term's original sense – refers to the process that sequentially deposits material onto a powder bed with inkjet printer heads. More recently the meaning of the term has expanded to encompass a wider variety of techniques such as extrusion and sintering based processes. 3D Printing Lighting products is expected to change the way half-fabricates and end products are made and set to change the supply chain. Technical standards generally use the term Additive Manufacturing for this broader sense.

There are several aspects in the lighting industry that 3D Printing can impact.

3D Printing Metal Housing and Components

Metal 3D Printing is a costly method as the metal printers use laser methods to manufacture any objects. Hence, metal materials are limited to high-end Lighting applications. Ceramics and others are affordable materials that are expected to have a high demand in future, for example to enhance fixture cooling. A range of other manufacturing materials can be used for 3D Printing that includes nylon, glass-filled polyamide, epoxy resins, wax, and photopolymers.

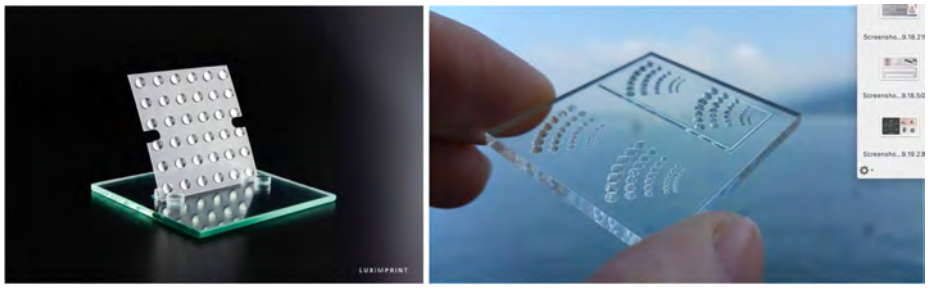

Figure 7: Digital fabrication of micro-lenses (courtesy of LUXIMPRINT)

For many manufacturers of Lighting equipment, natural convection of airflows remains the preferred method for cooling the electronic components of a given light fixture. This method is cheap, simple to maintain and produces no noise or electromagnetic interference. Natural convection, however, is limited in its scope. Metal 3D Printing opens up doors to design solutions that could help significantly to improve the efficiency of cooling bodies.

3D Printing Optics

3D Printing of optical performance parts (optics, lenses, reflectors) is a very niche technology in the Additive Manufacturing landscape. On the contrary, to more common technologies where mainly accuracy of shape matters, the parts also relate to a given function in its total optomechanical assembly. In addition to shape accuracy and form fitting, other factors like transmission values, refractive index, haze values come to play. Due to the deep skills needed to design and manufacture optical parts and understand their performance, only a handful of companies around the globe are in control of the process. One of these is the Netherlands-based LUXIMPRINT, a global leader in Additive Optics Fabrication.

3D Printing Personalized Components, Accessories and Services

3D Printing provides a more flexible, fast and more environmentally friendly way to manufacture luminaires and lighting devices. Signify, a company leader in the world in Lighting recently unveiled its facilities to 3D Print light shades and luminaires in the Netherlands. Over recent years, the company has perfected a highly flexible, digital, more sustainable form of manufacturing, using a 100% recyclable polycarbonate material. It allows luminaires to be bespoke designed or tailored to customer's exact needs and recycled at the end of their life, supporting a circular economy. The investment in 3D printing further illustrates the commitment to better serving customers while reducing their, and their company's, carbon footprint. A typical manufactured luminaire (excl. electronics and optics) using recycled materials and 3D Printing can reach a 47% lower carbon footprint than a conventionally manufactured metal luminaire. Nearly every component may be reused or recycled, supporting the concept of a circular economy.

With the EU H2020-FOF-2017 funded project Repro-Light (Grant number 768780 – https://www.repro-light.eu/), the company Grado Zero Espace from Italy, specialized in advanced materials R&D and innovative manufacturing technologies, has had the possibility to experiment the concept of 3D Printing customization and modularity strategy for Lighting luminaire manufacturing and installation packs. Starting from Repro-Light project ideas and installation requirements, the Company has developed integrated installation plans including 3D Printing elements, for linear and pendant solutions, highlighting and analyzing the importance of Eco-Design through concepts like Design for Disassembling, extended life cycle, maintainability, upgradability, etc., through the use of digital generative technologies.

Coverings (in 3D Printing in one piece and two pieces for housing), reflectors on shading covers (aesthetic and functional),

Figure 8: Infographic and tailored decorative luminaires (courtesy of Signify)

Figure 9: Coverings in 3D Printing metal and plastic (courtesy of Grado Zero Espace)

anti-glare components, connecting elements, and complementary accessories modules (projector, Bluetooth, etc.), have been experimented on within the Repro-Light project, as well as customizable installation packages configurable packages based on the type of installation for office, retail and industry spaces.

Based on the different types of installation, it is possible to define product specifications aimed at the specific scenario package and manufactured on-request through 3D Printing, for no stock for small production and on ad-hoc scale.

Conclusion

Novel rapid production technology, such as 3D Printing, is a disruptive innovation due to its potential to induce large-scale changes in multiple conventional industries, supply chains, and business models. It also promotes one to one relationships between customers and manufacturers. This is particularly interesting and true for the lighting industry, where it is crucial to understand how this revolution in manufacturing will have implications for not only the manufacturing processes, but also on the business model by seriously augmenting or replacing current systems of manufactured production and consumption, which may all occur at a distance. Rapid production has the potential to impact and revolutionize the business models and supply chains we know today. The creative evolution of rapid prototyping towards rapid product design and manufacturing and rapid product development will continue to generate a variety of new environments to design and manufacture products with broad capabilities for meeting customer expectations. (Bernard & Fischer 2012). Firms that do not adopt rapid production technology will be at a disadvantage, in the near future. With 3D Printing, the manufacture of individual lighting components, such as heat sinks, electrical traces, and LED optics, customizable accessories and installation packages, shading elements etc., could be customized, enabling the design of parts that cannot be manufactured today by traditional methods, improving both aesthetics and functionality. Research is still needed to advance the integration of 3D Printing into the lighting industry, beyond the current prototyping stage. Several projects such as the Repro-Light H2020-FOF-2017 project have been funded by the EC to conduct initial investigations into the potential for 3D

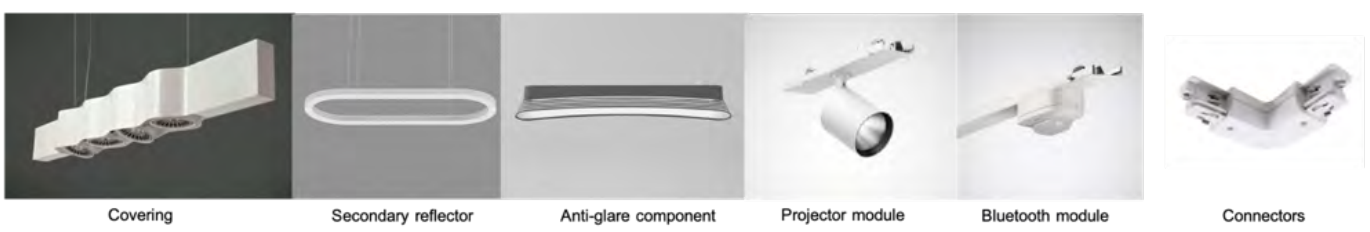

Figure 10: Complementary accessory modules by 3D Printing (Courtesy of Grado Zero Espace)

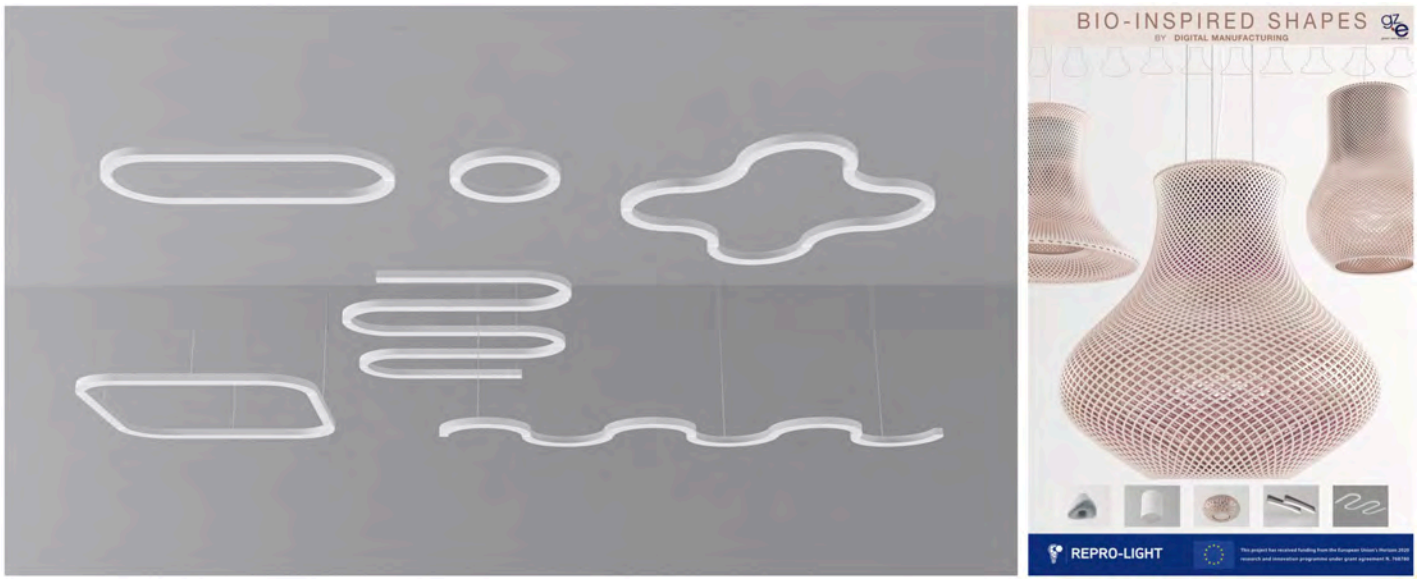

Figure 11: Modular connectors and bio-inspired shapes by 3D Printing (courtesy of Grado Zero Espace)

Printing aesthetic and functional components, for linear and pendant lighting systems. ■

Acknowledgement

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Repro-light — Following a User-centered Design Approach to Develop the Luminary of the Future

The EU-funded project "Repro-Light" has set itself the goal of analyzing the future of luminaires. The project team will comprehensively approach the task and examine the entire life cycle of a lighting system. In his report, Dr. Ganix Lasa from Mondragon University in Spain, documents the results of comprehensive surveys on the needs of users.

The European lighting industry is moving towards a more sustainable and competitive future. Luminaire manufacturers are harnessing innovative technologies and new materials to design new lighting solutions, trying to improve mankind's everyday life and wellbeing. However, one of the key aspects of this process is to integrate a user-centred design approach. Including the user perspective into the design process will ensure that innovative lighting designs fulfil specific needs of end-users.

As part of the European Commission's Horizon 2020 work programme, the REPRO-LIGHT project ("Re-usable and re-configurable parts for sustainable LED based lighting systems" www.repro-light.eu) aspires to implement this process in a leading European luminaire manufacturer and thus demonstrate a possible way to transform the European LED lighting industry by creating the 'Luminaire of the Future'. Thus, in this European project a specific user-centred design process is followed during the whole development process.

The report presents how the REPRO-LIGHT project takes user needs and requirements into account to set the future of the luminaire. On the one hand, it describes how the users have actively participated in the process at the early stage of the project by means of focus groups with different stakeholders and a questionaire filled out by 1,096 participants across four European countries. On the other hand, the paper describes how a list of technical requirements has been set based on insights obtained from activities previously mentioned, using the Quality Function Deployment (QFD) technique.

We are convinced that, based on the results of the user centered design approach, people are ready for the next big steps in transforming workplace lighting, i.e. personalized workplace lighting. Furthermore, technology and production processes are also ready to start this transformation process.

Introduction

The lighting industry is facing a transformation, where the future of the industry seems to be even more competitive. Companies are trying to improve mankind's everyday life and wellbeing by developing more innovative concepts where sustainability has become an important aspect. However, one of the key aspects of the new concept is to integrate the User Centered Design (UCD) approach into the design processes. The UCD concept is a broad term that describes design processes where stakeholders take part and influence the final design solution. There are different tools and techniques to do this, such as surveys, focus groups and user testing. Including the user perspectives in the design process ensures that innovative lighting designs fulfil the real needs of users.

Personalization is currently a topic of importance in the Information and Communication Technology (ICT) sector. Due to the increasing integration of ICT in lighting, personalization has also become an important topic in the lighting industry. However, due to the novelty of this technology for light experts and the lack of expertise, current developments are still in an exploratory phase and associated requirements have not yet been defined.

The REPRO-LIGHT project is following a user centered design approach by applying different sorts of tools and design techniques. On the one hand, it shows how the project has implemented a co-creation strategy based on five different focus groups with different stakeholders. On the other hand, results from a comprehensive, web-based questionaire on workplace lighting is shown. 1,096 people from across Europe rated their current workplaces and noted the changes in lighting they thought would improve their productivity, mood and performance. Finally, the paper describes how the Quality Function Deployment (QFD) [1] technique has been used to find the correlation between previously collected requirements and design attributes of the luminaire. The technique is based on a correlation matrix and also called the House of Quality (HoQ).

Methods

Focus groups

According to the Cambridge dictionary, the definition of a focus group is “a group of people who have been brought together to discuss a particular subject in order to solve a problem or suggest□ideas” [2]. The activity is commonly used as a market research method to provide feedback regarding a product, service, concept, or marketing campaign.

As a method, it has become well established in the early stages of product / service development [3][4]. The REPRO-LIGHT project used five focus groups in different countries to support the luminaire development process:

- 1 Focus Group in Spain with 19 end-users
- 1 Focus Group in Germany with 9 Lighting Experts (Light designers, Installers, Facility Managers)
- 3 Focus Groups in Austria with (i) 9 Light designers, (ii) 11 Lighting Researchers and Luminaire Developers and (iii) 4 people from the Management Board of a lighting design company.

The goal was to derive technical specifications for the REPRO-LIGHT luminaire which are based on a comprehensive evaluation of core limitations of current workplace lighting systems and the systematic collection of expectations with regards to personalized workplace illumination in the near future.

Inorder to reach this objective, opinions, needs, motivations and expectations for future luminaires were collected from the stakeholders who came up with innovative ideas that would add value to current solutions or be developed in the future.

The moderators of the focus groups were members of the REPRO-LIGHT consortium. Their role was to be responsible for a structured process, not the content.

Generally speaking, the key questions for end-users with regards to personalizable (end-user creates a lighting solution based on pre-defined features) and customizable (luminaire adaptable by professional or end-users) lighting were the following:

- Are you interested in using a customizable lighting system?
- Do you think you would feel at ease using digital devices to control personalizable lighting systems?
- What features would you like to personalize?

Furthermore, lighting designers and developers were asked the following two questions:

- What features would you like to personalize?
- Are you interested in customization?

As a main structure, all focus groups were divided into three main phases: Introduction, Central phase or Creative phase, and Closing. Based on this, each focus group adapted its content and tools according to the profile and number of participants [7]. Referring to just one focus group made up of end-users, the central phase of the session was subdivided into four main activities; user scenarios creation, billboard design, brainstorming session and an idea dissection activity. Each activity was 20–30 minutes long (**Figure** 1).

User scenario activity was the first technique proposed for the session, and participants had 30 minutes to develop this activity. The objective of this tool was to get descriptions from the users of how they imagine the future luminaire systems would be by using contextualization of Office, Industry, Retail and Care. To focus the attendees efforts and to develop the acitivity correctly, four templates (office, industry, retail and care scenarios) were provided to each group as visual aids.

The second exercise, “Build a Billboard”, focused on summarizing and simplifying all the clues and ideas collected from the characteristics that users generated in the previous dynamic (user scenario creation). Participants had 20 minutes to develop the activity. Users had to use billboard templates to visually summarize and simplify the most important insights or data gathered from each scenario as well as prioritize the ones that they considered more relevant (office, industry, retail and care). The steps to fulfil the activity are the following:

1. Select four most important insights gathered in each previous scenario for each characteristic.
2. Prioritize the most relevant insights and add to the billboard

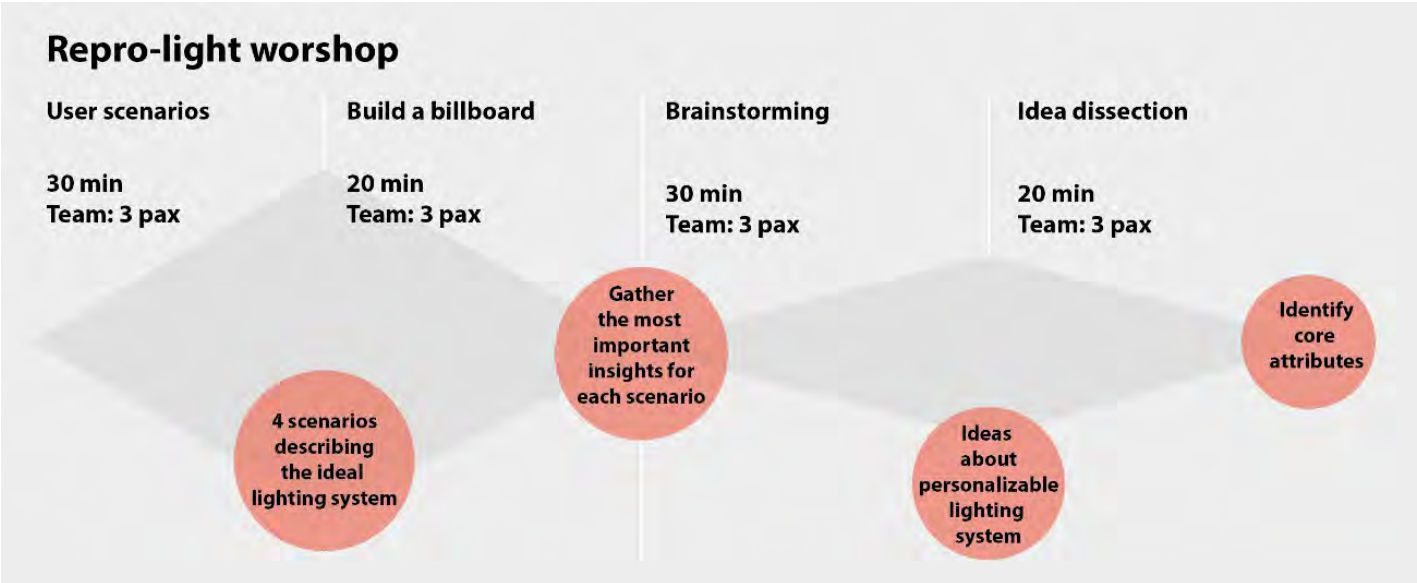

Figure 1: End-user’s focus groups planning

3. Move the templates between different teams in order to perform the next brainstorming activity

The focus group continued with a Brainstorming, for that, participants had 30 minutes. The activity is about generating as many ideas as possible related with those ideas listed in the billboard, always without any kind of restriction and in an effective way. In this specific focus group the aim was to generate ideas about personalizable lighting systems. To achieve these solutions, workshop participants had to think of new opportunities to improve the current lighting sector along with their needs.

The Idea Dissection activity was performed in order to finish off the central phase of the focus group. This tool converges the ideas gathered during the brainstorming and helps to select the best one. The participants of the focus group had 20 minutes to identify core attributes and create a future scenario based on them after completing the activity. Before ending the session, moderators had an open-discussion with all attenders and collected a few new insights and conclusions from each group.

At the end of the session all the insights were collected and analysed. First, the ideas collected were compared to avoid repeating similar concepts. After that, results extracted from user scenarios and billboards were analysed and ideas were grouped, taking into account the context of use and the requirements for personalization. On the other hand, the needs collected in the brainstorming session and selected in the activities of ideas dissection, were analysed and grouped by context and characteristics typology. The results were used as a requirement for the REPRO-LIGHT QFD.

End-user questionnaire

A web-based survey, delivered by the online Limesurvey platform [5], was compiled to quantify end-users' acceptance levels of their current workplace lighting (9 questions) and to further derive requirements for customizable and personalizable lighting systems (13 questions). The full questionnaire is available on `http://bit.ly/ReproSurvey`.

The survey was translated into four languages, i.e. English, German, Spanish and Italian, to enrol subjects from all European states of the REPRO-LIGHT consortium. In total, 1,278 end-users answered the questionnaire. Only questionnaires filled out by end-users in the application fields "Office" (87%) and "Industry" (13%) were included (1,096 in total) in the analyses.

House of quality

For the development of a new product, it is essential to know what the customer really wants to have, or, especially for innovations, what is proposed to generate customer benefits. Standard Quality Function Deployment (QFD) often generates the list of requirements by directly asking customers or users of the product to develop. Unfortunately, this method will only deliver requirements the customer already has in mind. Requirements for breakthrough inventions will not be found by just asking customers or end-users. Therefore, the REPRO-LIGHT consortium decided to use a slightly different approach, collecting information from all stakeholders.

The following steps were taken to develop the REPRO-LIGHT House of Quality:

- Recording of requirements.
- Standardisation of requirements.
- Prioritizing the requirements.
- Definition of design attributes.
- Evaluation of design attributes.

After recording the requirements, as a first step we translated the original and raw requirements to a standardized level (same degree of technical and application abstraction for all requirements; initially some requirements were formulated with technical details, others described application needs very unspecific) and tried to make the requirement explicit and precise. In the same step we divided between System Requirements (to be fulfilled by system software or system layout) and luminaire requirements.

Sharpening the requirements in this way and focussing on luminaire requirements reduced the number of requirements from 80 to 37. For prioritizing them we decided to rank them on a scale of 1 to 9; 1 being of very low importance and 9 being of utmost importance.

When deriving the design attributes, it should be taken into account that the description of the characteristics is abstract enough that it will not restrict the function or the technical design to a great degree. Thus, REPRO-LIGHT determined a list of design attributes by way of brainstorming the requirements. These specific design attributes were internally discussed and amended in a workshop by partners. Using this method, a total of 72 design attributes for the REPRO-LIGHT luminaire were determined together with the target value for each one.

Based on these 37 requirements and 72 design attributes, 2,664 influencing factors were defined. Each factor was evaluated by answering the question: "If design attribute X is realized in the REPRO-LIGHT luminaire, how much does it contribute to fulfill requirement Y", and asking for a value on a scale of 0-1-3-9 (from no influence to high influence).

For the evaluation of the HoQ, design attributes were grouped according to luminaire subassemblies the attribute is connected with (design attributes connected with LED, driver, connectivity, firmware, mechanics, optics, sensors, modularity) and the evaluation itself was done column by column. Finally, the rating for each design attribute was calculated (1):

$$R_i = \sum_{j=1}^{n_r} P_j \cdot I_{i,j} \qquad (1)$$

R_i Rating for design attribute $_i$
P_j Priority of requirement $_j$
$I_{i,j}$ Influence factor of design attribute $_i$ to fulfill requirement$_j$
n_r Number of requirements

The higher the rating of a design attribute is, the more it will contribute to requirement fulfilment, and thus the most important requirements are obtained and listed for the following design phases.

Results

REPRO-LIGHT has implemented a user-centred approach to understanding user needs and developing a new luminaire concept based on the requests. In the first phase of the project, this activity focused mainly on the focus groups, the questionnaire and resulting QFD.

Regarding the focus groups, the presence of different professional groups from the lighting sector has led to diverse replies concerning modular luminaires. As a general observation, it was found in all focus groups that the topic of sustainability and circular economy receives little attention in the daily business. However, exchangeable modules for longer lifetime have been rated useful, especially for the installers and customers (facility managers). In combination with analysis and monitoring opportunities based on sensors and communication modules, this enables simple maintenance services. Different

focus groups mentioned benefits for personalized lighting, when data collection and data protection are in accordance with privacy policy and light intervention algorithms are derived from research results (biological effects of light, non-visual and visual effects of light). In all focus groups, it was mentioned that there is a risk of missing design and aesthetic aspects when developing modular luminaires (one size fits all). This can be avoided by giving the customers and end-users the ability to create individual luminaire housings.

The findings from the questionnaire reveal that current lighting in the workplace is not satisfying end-users and their needs, while at the same time it has a big impact on productivity and human wellbeing. It should be highlighted that 55% of end users said they would like a better workplace lighting. The survey showed, that the individual requirements for the lighting differ, showing that personalizable lighting is needed to satisfy all the users. It is not only the need to improve light, over 50% of participants said that the physical luminaire aesthetics where important to them, especially for workers that are under 30 years old. Moreover, 80% of the participants would like to have workplace lighting, which automatically adapts to personal needs, and more than the 75% would like their work light to change color when it gets dark outside (**Figure** 2). All of these factors play a role in the greater impact of lighting on the workforce of Europe, and more than 90% of participants stated that they believe their work lighting can affect their mood [6].

The full report can be downloaded from REPRO-LIGHT website `https://www.repro-light.eu/downloads`.

In the following, the main requirements based on the REPRO-LIGHT user-centered approach (end-user survey and focus groups) are summarized:

Requirement 1: Provide easy-to-use interfaces for the end-user to adjust light settings (especially for adult workforce)
Requirement 2: Respect past experiences of end-users with adaptable lights and consider their familiarity with user-interfaces (“Step-by-Step”)
Requirement 3: End-users want to adapt brightness, light color and light intensity distribution of lights and do this solely via software
Requirement 4: End-users want to adapt the spatial position of the luminaire manually
Requirement 5: End-user interaction with the lighting system should be minimized (provide automatic lighting and allow users to interact with the control system)
Requirement 6: Different visual demands require personalized light settings
Requirement 7: “Owned” workplaces deserve personalized lighting
Requirement 8: Aged eyes need personalized light settings
Requirement 9: Provide zonal lighting to illuminate restricted areas with personalized light settings (relevant for shared workspaces)
Requirement 10: End-users like daylight; thus, integrate daylight in personalized lighting designs (e.g. sensors)

In addition, the following four core design attributes for a REPRO-LIGHT luminaire were derived from QFD and the HoQ process [8]:

Figure 2: Survey results infographic

Connected lighting is very important to realize a REPRO-LIGHT system. Both wired connectivity and wireless connectivity got the highest ratings as design attributes.
Dynamic lighting for changing light in all three dimensions (intensity, color, and direction) is also very important. Dynamic lighting forms the basis for Human Centric Lighting, personalized lighting and adaptable lighting due to changes in environment.
Exchangeable and upgradable components and firmware. This requirement provides the platform for a circular economy of future luminaires and covers drivers, LED modules and optical modules. Furthermore, this design attribute will make it easier to adopt luminaires to a personalized usage of light and to adopt luminaires to changing environments and steady improving lighting technologies.
Efficiency is not the most important design attribute but it still has a medium-high rating.

Conclusion

A UCD approach was applied at the early stage of the REPRO-LIGHT project. In this regard, and as part of the first phase of this project, both the focus groups and the questionnaire, set out to investigate the wishes and needs of end users' future workplace lighting systems.

Regarding the focus groups, the presence of different stakeholders has led to diverse replies concerning modular luminaires. In all focus groups with different stakeholders it was found that the sustainability issue and the circular economy receives little attention in daily business. However, exchangeable modules for a longer lifetime have been considered useful, especially for installers and customers (facility managers). In combination with analysis and monitoring opportunities based on sensors and communication modules, this enables simple maintenance services. The ideas collected during the focus groups are relevant and valuable, collecting insights from end users, customers and other stakeholders for presented contexts from different lighting applications.

The result obtained from the questionnaire, demonstrated that a change is required in the working environments, both in industrial workplaces and in offices, and that people are already prepared for the next large steps in lighting transformation. They demand personalization, automation and adjustability to match their requirement and, most importantly, to increase productivity and overall wellbeing.

Finally, the QFD technique enables the prioitization of the requirements that REPRO-LIGHT solutions should integrate. Interpretation of the rating for the design attributes showed that Connected Lighting, Dynamic Lighting, exchangeable and upgradable components and firmware and Efficiency should be taken into account in order to meet customer satisfaction with the future luminaire.

Based on these results, REPRO-LIGHT will maintain this human-centered luminaire approach throughout the entire project in order to ensure that user needs and personalization preferences are well addressed. To do so, the project intends to perform evaluation tests and assess, among other things, the acceptance level of the provided solution throughout the development of the project. ■

Acknowledgement

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Offline Lighting Voice Controller — An Alternative to Voice Assistants

The historical evolution of light control by users started with a mechanical switch followed by potentiometer and dimming, touch panels and touch screens, gesture and movement detection control, and ending with voice. Voice control are mostly online speaker independant like Alexa, Google Home and Siri. But there are privacy and security concerns. Filip Michalski, Electronic Engineer, and Cezary Skotak, CEO, from Cezos describe a speaker independent offline voice controls system, explain the technology and discuss the pros and cons.

Artificial light was always linked with the need to control it. For many years it was only a simple on-off control, which was done by a switch on the wall or on the power cord. In the recent years, the need arose from the change in lifestyle combined with the development of technology that has enriched the spectrum of available options. The development of technology in conjunction with lifestyle changes meant that lighting control now plays the role of the most popular and cheapest function of an intelligent home or building.

A Short History on Controls

The development of electronics meant that the simplest lighting control of the on-off type used in cable circuits, was enriched by the ability to control the power of light bulbs, which allowed to regulate their luminous flux. Although the maximum brightness of the lamps remained unchanged, and thanks to electronic dimmers, it could be reduced, i.e. dim the incandescent lighting below the maximum level.

There were some problems with it, such as the frequent acoustic effects of dimmers in the form of annoying buzzing and the costs of the equipment itself, which significantly limited the spread of this control method.

Electronic dimmers – slide, rotary knob or touch – were installed instead of the usual switches and could work with all traditional bulbs. Unfortunately, in the case of halogen bulbs there were significant problems in the form of a decrease in their durability. Dimmers were also not compatible with energy-saving compact fluorescent lamps, which largely displaced traditional incandescent bulbs from home use. In the next phase, wall touch panels began to be created, and thanks to e.g. home automation systems, it was possible to control the entire building from one point. The alternative control methods were infrared controllers and radio controllers, which could be controlled by a remote control.

The mass introduction of LED light sources for home use has become the limit of the possibility of using dimmers in the old, classic form. The overwhelming majority of LED lamps with the shape and size of traditional incandescent bulbs are incompatible with such old dimmers, and the price of LED lamps specially adapted for this is high. In turn, LED modules and strips require a special controller, which increases installation costs.

Further lighting control options, primarily LED lighting, appeared along with the mass spread of mobile phones, especially smartphones. Wireless lighting control systems have developed that use the Bluetooth standard for communication. Applications installed on smartphones have become a perfect, intuitive interface. This eliminated the need to approach the control board, because everyone could use their own, portable telephone usually kept within reach, to send commands wirelessly.

Despite their functionality in the mentioned drivers, the problem of the requirement to have a telephone or remote control at all times remained. These modern systems in which the interface is a smartphone require the user to be able to configure it. Some people who use mobile phones on a daily basis only use them for conversations and this is where their skills end. For them, such a configuration, although usually simple, turns out to be too difficult.

Figure 1: Proxi Dimmer On Board, gesture sensor with a LED module integrated

That is why systems with alternative operating methods are constantly being developed, which are becoming more and more popular. One example of a modern solution is the gesture control system, i.e. hand movements – ProxiDimmer. The controller, through a proximity sensor, can recognize the on-off gesture when moving the hand and lighten-dim when holding the hand over the sensor, and optionally change the color of the light. It is a very functional and aesthetic solution because it does not require touching the switch or panel. It also solves the problem of positioning the button, because the sensor can be placed next to the LED light source

or even between the diodes (ProxiDimmer OnBoard), which allows to uniform light.

From the user's point of view, the most convenient way to control the light, e.g. when his hands are occupied or when the switch, remote control or telephone i.e. are out of reach, is to use voice commands. This is the most intuitive and fast control. We simply say the command specifying what, where and how we want to change, and the system recognizes and executes it.

Voice Control — The Technical Basics

This technology is not as modern as it may seem. It has existed for a long time, but it has always been limited by hardware and software capabilities. Despite this, the producers saw its potential. One of the first examples of its widespread use was voice dialing on mobile phones in the days before the popularization of iOS and Android. Unfortunately, the limitations of this technology were clearly visible and therefore it remained in the sphere of technical curiosities.

Comparison of Different Approaches for Voice Control

The simplest voice control system is the Speaker dependent one. We need to teach the driver specific commands issued by our own voice, and then he will be able to recognize and execute them. The speaker-dependent voice control system is the cheapest and the simplest solution. A good example of the location of such a system is a desk or bedside lamp. In this case, we usually deal with only one person controlling this lamp. The advantage of such systems is low power consumption, which it allows it to be battery operated, and no language barriers – the device only recognizes the pronunciation of a given command. It is limited by the need to configure commands that may seem tedious, and the limited number of them to configure.

The VOICEEMITY Dynamic White Speaker Dependent controller has the following parameters:

- Operating voltage: 11–27 V DC
- Application: Constant Voltage LED stripes and modules
- Output current: 9 A/CH
- Detection distance: 1–2 meters
- Size: 70×27.5×15.5 mm

Figure 2: Offline Speaker dependent voice controller

Voice assistant systems – Alexa, Google Home or Siri, which require Internet access – ONLINE system gave a significant acceleration. These solutions allow for many other activities such as checking the weather or traffic, and of course lighting control. All you need to do is buy a compatible light bulb or a system for LED strips or modules (e.g. HOMEEMITY) and you can enjoy the perfect system to control lighting using your voice. These systems also allow you to automate activities such as automatically turning on and off lights, grouping devices and many other things. Perfect? Not completely. These systems have not yet overcome the hardware limitations, which is why they require constant internet connection – because it is in the cloud that our voice is analyzed. The device responds only to the key word (WakeWord) such as "Alexa", "Ok Google", and then these words are sent to the appropriate servers.

It's a kind of problem, because you have to have the internet connection at all times. It's not about the lack of connection to the internet or about interruptions in supply, failures of your internet provider or your WI-FI router. Lack or failure of one element from this chain means no control over the light. An additional problem is the requirement to configure the voice assistant and each device (lamp), and it is, as we have seen, a challenge for many people.

The most interesting solution is a voice control system independent of the speaker (Speaker independent) which does not need the Internet to work (OFFLINE system). The system is always designed and built into one specific device, i.e. lamp above a table. Advances in hardware (price and capabilities) and software (reducing hardware requirements for power and memory) have allowed us to match quality with voice assistants that require the

Feature	Voice Assistant	Speaker Dependent	Speaker Independent
Internet Required	Yes	No	No
Complexity of Configuration	Hard	Average	Easy
Detection Distance	Good	Average	Good
Grouping Possibility	Yes	Optional	Optional
Automation Possibility	Yes	Optional	Optional

Table 1: Comparison of individual voice control systems

internet. Of course, such a device will not tell us the question of what the weather will be like tomorrow or what the traffic will be like, but it has several key advantages:

- It doesn't require the internet, which makes it independent of it.
- Complete lack of configuration, plug & play system with enough capabilities for light control.
- We talk straight towards the device – a lamp that has its own built-in microphone.

As the previous systems are closed source – i.e. we don't know what is under the "hood", the speaker independent system is designed in collaboration with our voice recognition specialists. In this system two parts may be distinguished: key word spotting part and commnads recognition. To minimalize delay and preserve consistency, both of those tasks are realized with the same acoustic model. For acoustic modeling LSTM (Long short-term memory) recurrent neural network is used. Network is trained using CTC (Connectionist Temporal Classification) cost function.

Figure 3: Offline Speaker independent voice controller

To satisfying on device performance, inference of neural network is highly optimized with quantization, taking into consideration ARM SIMD. Key word spotting is realized with CTC scoring algorithm. Commands recognition operates on beam search algorithm with limited vocabulary. Generic approach for acoustic modeling does not restrain domain and allows for high flexibility in target Implementation.

The VOICEEMITY Dynamic White Speaker Independent controller has the following parameters:

- Operating voltage: 11–27 V DC
- Application: Constant Voltage LED stripes and modules
- Output current: 9 A/CH
- Detection distance: up to 5 meters
- Size: 70×27.5×15.5 mm

Differences between the presented systems

The above **Table** 1 shows the comparison of individual voice control systems.

How to Choose the Appropriate System

If we want to make a complete home automation system, an online voice assistant system would be a perfect choice. Ability to group lights, create automatic tasks (routines) is a great addition. It is also capable of many different tasks beyond light control, and thanks to constant updates, it is getting smarter. The requirement of constant connection to the internet can be solved by adding an external switch or control option (i.e. gesture control), which would work parallel to the voice control. When we are concerned about data privacy, we don't want to rely on the internet connection or the configuration could be troublesome for you or your costumers, an offline system is an alternative solution.

With speaker dependent system, the configuration could be somewhat of an issue, but it is still easier than a voice assistant. It is designed for lamps closer to the speaker (the detection distance is the lowest of all described systems) and most suitable for personal lamps i.e. desk or battery operated lamps. While the system above is not suitable for every lamp, the speaker independent solution is a solution for every lamp. No configuration, detection distance the same as an online system, privacy guaranteed by design. Also worth noting, each lamp has its own microphone, so we can put them wherever we want – no need to place a voice assistant system nearby to get the voice control. This technology enables you to easily create smart lamps, that are usable in everyday use and are easy to configure for you and the customer.

Conclusion

While every system has its advantages and disadvantages, the user themself must decide on the solution that is the most suitable for them. While the online voice assistant systems are constantly improving and work is being done to allow the user to control the devices (i.e. light) when the internet is down, a parallel solution (Gesture, Touch Button and so on) is practically a must-have to be suitable for everyday use. This is true for every voice control system. While an Offline voice control systems can never replace an online system because of the added capabilities, it can be an interesting alternative. ■

ABOUT THE AUTHOR

Cezary Skotak: Cezary Skotak is founder and CEO of a family business. The company, founded in 1981, is a producer of plastic and metal parts for the manufacturing of lamps. In 2005, in strong cooperation with Osram OS, a strong partner in the LLFY platfrom, activity was expanded to include the production of LED modules and electronics to control them. The year 2016 was the beginning of work on a new generation of voice-controlled lighting.

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Smart Connector — A New Solution for Smart Lighting

Intelligent lighting solutions are often requested but just as often, installation and costs hinder the final implementation, especially in existing building environments. A cost-effective, yet powerful solution is required. Dr. Hugo Pristauz, CTO & co-founder of the Austrian startup company Bluenetics, together with CEO and co-founder, Ing. Rainer Reiter, explain and demonstrate a solution that offers the required flexibility needed to upgrade existing homes to smart homes.

Home automation with and without voice control is in line with the trend. Affordable, simple and reliable solutions are required. The authors present a new solution that sets a new benchmark. A smart connector that finds its place in a flush mount box to upgrade conventional switches, pushbuttons, or sockets with Bluetooth® (SIG) Mesh.

Introduction

While wire based smart control has established strong standards in lighting and home automation during the past 30 years, the future trend is definitely wireless. The trend "going smart" yielded in more than 1.5 billion smart phone unit sales per year, but with the massive evolution of the internet-of-things (IoT) the expected number of wirelessly communicating devices in smart home and lighting applications are expected to be much higher by the end of next decade. According to IDC, by 2022 the smart home market is expected to already reach 1.3 billion devices, including smart speakers, video entertainment products, connected lights, smart thermostats, and home monitoring/ security products. The five-year compound annual growth rate (CAGR) will be 20.8% [1].

A major reason for the big trend from wire based to wireless is obviously the ease of upgradability leveraged by wireless solutions. Especially in the home-automation area, estimates are that 80% of new smart homes are implemented through upgrades, where wireless upgrades leverage the benefits of simplicity and cost efficiency due to avoidance of tedious, dirty and expensive construction work. Another positive aspect is that wireless smart home installations can be easily moved to a new home.

An interesting approach to smart home upgrades is by means of smart connectors, which are tiny enough to fit into flush mount boxes behind switches, push buttons and sockets. The smallest kind of this species is now offered by Bluenetics ("bluco" – Bluenetics Connector) with dimensions of 36×30×13 mm, to be launched at Light and Building 2020. Designed as a universal flexible Bluetooth (SIG) Mesh [2] device, it combines the functionality of a wireless controlled switching actor, dimming actor and wall switch sensor, suitable for smart light control in home environments.

The Bluenetics smart connector has one dimmable 230 V~ output which can drive max. 2 A or max. 400 VA, and can thus drive the majority of 230 V~ direct powered luminaires, as long as they are equipped with dimmable light bulbs. The availability of dimmable 230 V~ powered LED-bulbs has been some issue in the past, but driven by the increasing demand the majority of LED-bulb manufacturers now offer cost effective 230 V~ powered LED products with sufficient dimming capability.

Simple Use Case

The simplest use case for a smart connector is shown in **Figure** 1, where a classical luminaire controlled by a standard wall switch is upgraded to a smart light control by insertion of a smart connector.

- Light gets dimmable with the option of smart fade-on/fade-off
- Simple scene selection (various dim levels for single luminaire) by double switch operation
- Timed fade-off (optional)
- Switch and luminaire are re-used (existing designs are maintained)
- Upgrade within 5–10 minutes, no dirty and expensive construction work

The benefits listed above so far require neither wireless communication, nor a wireless mesh network. A typical use case for a smart connector without need of wireless connectivity is light control of a child's room **Figure** 2.

The light is usually off when the child is sleeping (**Figure** 2 – left). If, in such a situation the child's room has to be visited, an operation of the switch turns light on in dimmed mode (**Figure** 2 – middle). If the switch is operated again after 5 seconds delay, the light will fade off. Only if the switch is operated two times between a 5 second interval, the light turns bright (**Figure** 2 – right). As an option a timer can be activated at the beginning of bed-time (by double switching), which leaves the light in dimmed mode and fades it automatically off after 15 minutes.

For the installation of the smart connector there are several choices:

- Behind the switch in the flush-mounting box
- In the luminaire's outlet
- Behind a power outlet in the flush mount box, if the luminaire is connected via a power plug (free standing luminaires, bed-side lamps)
- Inside any flush-mounting distribution box on the path from the switch to the luminaire

Especially in the case when a smart connector has to fit behind a switch or socket, a small form factor is crucial. For example, for 45 mm deep flush-mounting

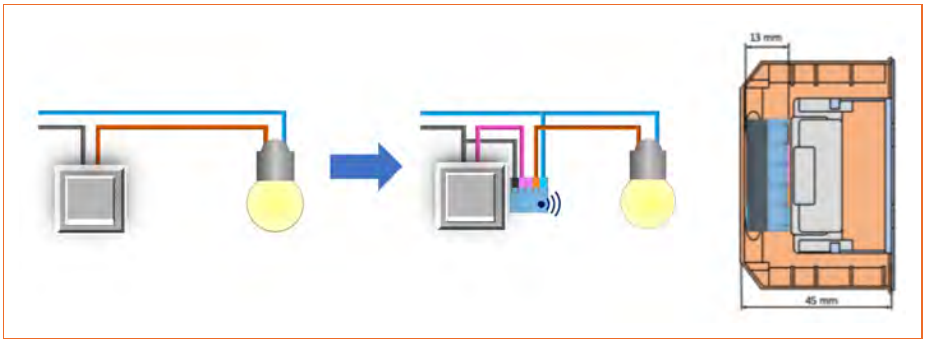

Figure 1: Smart connector used for smart home upgrades, fitting into flush-mounting boxes behind switches, push buttons and sockets

Figure 2: Light control of a child's room: off (left), dimmed (middle) and bright (right)

boxes the remaining space for a typical switch or socket insert is max. 13–14 mm (**Figure** 1).

Bluetooth Mesh Networks

The full advantage of smart connectors comes on the scene when Bluetooth (SIG) Mesh [2] is utilized. Mesh technology allows Bluetooth devices to be linked together to form a large network. By the extension of Bluetooth 4.0 with Mesh, thousands of devices can now be connected in a network and thus communicate with each other over long distances in an energy-efficient and secure manner.

Additional benefits being supported by Bluetooth® Mesh are:

- Selection of scenes with multiple luminaires
- Central on/off
- Relay function of a smart connector to increase communication distance
- Remote control via smart phone or tablet
- Central firmware over-the-air update (OTAU)
- Voice control

Highlights of Bluetooth Mesh [2]

- Bluetooth Mesh is an open standard with strong focus on interoperability [1], which allows easy connection of devices from different vendors. This is by far the most important aspect of a winning wireless communication technology and an absolute must for a breakthrough to a dominant standard.
- Bluetooth Mesh is a worldwide standard and can be operated in every country of the world.
- Messages can be relayed from one device to another, thus overcoming communication distance limits, while enabling point-to-point communication for each device over the whole network.
- The self-healing property makes Bluetooth Mesh one of the most reliable networks and ensures its wide scale use in smart homes and lighting for the first time. "Self-healing" means, that a communication path will be automatically re-routed if some network device fails.
- Smart phone and tablets can directly communicate with Bluetooth® Mesh networks, which allows direct communication without gateways and is required for a simple on-boarding and configuration process. This overcomes existing issues of competitor technologies like ZWave, Zigbee, and various proprietary sub-GHz standards.
- Bluetooth Mesh defines decentral control capabilities running on the mesh devices, which makes central controllers (single point of failures) obsolete.

Scene Selection for a Bedroom

Consider a bed room with three luminaires (**Figure** 3), a ceiling lamp (A) and two bedside lamps (B, C). There are three simple on/off switches, one at the door (X) and two at the sides of the bed (Y, Z).

A smart home upgrade based on Bluetooth® Mesh smart connectors for a partner-friendly light control of a bedroom is proposed with the following control scheme:

- For all of the three switches the same function is assigned, which makes light control simple and straight-forward.
- If light is off and any of the switches is toggled, scene 1 is selected (**Table** 1) with ceiling lamp off and both bed-side lamps dimmed. This is the partner-friendly scene, suitable for one partner entering the bed room while the other partner is already sleeping.
- If a light switch is operated again within 5 second interval, a subsequent scene is selected according to **Table** 1. Such a control scheme enables any switch to select an alternate scene, i.e. turning both bedside lamps bright, left bedside lamp only, right bed-side lamp only, and all luminaires turned on (bright).
- If light is on (any scene) and a switch is operated later than 5 seconds after last switch operation, the light is switched off.

The specific dim levels of the luminaires can be set up per each scene with a smart phone or tablet, which usually only happens once, at the initial time, while the actual scene selection is performed via switches.

To implement the smart home hardware upgrade, three smart connectors have to be installed, according to **Figure** 3 and the electrical schematics of **Figure** 4. The first smart connector is installed in the flush-mounting wall box behind the door switch (X) in order to sense the 230 V~ door switch state, and to control the dim level of the ceiling lamp (A). If there is no neutral wire in this wall box, another wall box can be found with a neutral wire on the path from door switch (X) to ceiling lamp (A). A second smart connector is installed in the wall box of left bed side switch (Y) in order to sense the 230 V~ switch state and to control the dim level of the adjacent power outlet for left bed-side lamp (B). In a similar way, a third smart connector is installed behind right bedside switch (Z), sensing the switch state and controlling the adjacent power outlet for right bedside lamp (C).

It is worth it to realize that hardware installation of the smart connectors and configuration and scene setup are two independent tasks that can be separated. The soft-interconnection of the devices is a very simple task in Bluetooth® Mesh networks. To accomplish this, two things must be done:

1. The first thing is to provision each smart connector, meaning to securely on-board the device into the mesh network. During this process a so-called "job" can be assigned to the device, which means to select a proper functionality. In the example above each smart connector would be assigned with a "Scene Selection Job".
2. The second thing is to create a so-called group (e.g. with name "Bedroom Light"), select the desired group's control scheme (e.g. "Scene Selection") and assign the group to each of the provisioned smart connectors.

Optionally, scenes can be finetuned with proper lightness levels using a smart phone or tablet. After completing these steps, every toggle of any of the three switches will perform either an on/off operation, or a scene selection, depending on the time interval between the switch events.

It should be mentioned that there is no central controller performing the control actions, which would potentially be a single point of failure. According to a basic philosophy of Bluetooth® Mesh, any control is performed at the edge, a possibility supported by the underlying Bluetooth® Mesh many-to-many topology, where each node can communicate directly with any other node of the mesh network.

Smart Connector Requirements for Suitable Smart Home Upgrades

In the final section, several requirements for smart connectors are listed that are an advantage for suitable smart home upgrade solutions.

Interoperability

Interoperability is by far the most important requirement, as it allows an easy and straight forward connection of devices from different vendors. In all cases of existing smart home solutions true interoperability requirements are more or less not met. Most of the systems are based on a proprietary standard and thus not interoperable per se. Z-Wave® and ZigBee® are open standards with a wide footprint coming close to true interoperability, but those systems suffer now from the deployment of legacy dialects being big road-blocks for interoperability.

Bluetooth® Mesh was launched with a strong claim on interoperability, to be controlled by forcing each vendor to run a certification process for the mesh implementation of new Bluetooth® Mesh products. Interoperability is defined by so-called Bluetooth Mesh Models, which are communication interfaces at the application level [3]. Since the inception of Bluetooth Mesh in July 2017, more than 370 Bluetooth Mesh products have already been qualified [4][5]. In early 2019 the Bluetooth Special Interest Group (SIG) has installed a 60 member strong subgroup to standardize mesh software interfaces for all kinds of smart home devices in order to empower interoperability in smart homes [4].

Figure 3: Smart home upgrade in a bedroom with 3 luminaires and 3 on/off switches

Scene	Ceiling	Left Bed Side	Right Bed Side
Scene 1	off	dimmed	dimmed
Scene 2	off	bright	bright
Sence 3	off	off	bright
Scene 4	off	bright	off
Scene 5	bright	bright	bright

Table 1: Bedroom lighting scene selection

Quick & Easy Upgrade

Utilizing wireless connectivity is a strong enabling factor, as it makes dirty construction work, a considerable cost factor, obsolete. Smart connectors are designed for quick and easy upgrades. The smart connector hardware is installed by an electrical engineer with a basic function configured. The detail configuration process is as easy as connecting a smart phone to a WLAN hot spot, or to post an image in Facebook. It can be done by the smart home users themselves, and will thus save unnecessary expert cost.

The separation of hardware installation by an installation company and the configuration by the consumer is a win-win approach: first, installation companies are usually not interested in supporting their customers with software configuration tasks for which they don't get paid. Second, as observed with smart phones/tablets, modern consumers see added value in customizing their smart environments themselves, as long as the process is sufficiently easy. For example, the majority of smart phone users has no desire in consulting a company for downloading and configuring their apps.

Human Acceptance Factor

Smart home upgrades must not come with compromises, otherwise there will be an acceptance barrier for some members in a household. People are used to the haptics and to the simplicity of conventional switching devices. Upon replacement with sophisticated sensor switch fields some of the household members feel uncomfortable with the different haptic experience, and they want the old way back.

Another classic pitfall is the case with dimmable luminaires which can only be operated with a smart phone/tablet. If the wall switch breaks the circuit then the operation with the smart phone does not work anymore. And vice versa if the lightness has been dimmed with the smart phone/tablet, then the lightness cannot be increased with the wall switch.

None of these pitfalls need to happen with the use of smart connectors based on Bluetooth® Mesh. The re-use of existing wall switches leveraged by smart connectors especially guarantees maintaining existing and accepted haptics.

Universality

Smart connectors have the big advantage that they can be designed as universal devices, which become their specific functionality after the configuration process. In the case of the Bluenetics smart connector the specific functionality is selected by assigning a "Job" during the provisioning (on-boarding) process into the Bluetooth Mesh network. The concept is comparable to the concept of a smart phone as a universal device, where apps (corresponding to "Jobs") give the smart phone its specific functionality.

Such a concept makes it easy for the consumer during the buying process, as he/she does not need to know exactly about the particular usage of the smart connector. An additional benefit of the universal approach can be leveraged by companies using smart connectors for their projects, as the number of stock-keeping units can be kept drastically smaller.

Wireless Mesh Communication

All highlighted features of Bluetooth® Mesh (world wide open interoperable standard, relay mechanism, self-healing, smart phone/tablet direct access, many-to-many topology, decentral control) are essential for a new powerful wireless communication standard. Mesh technology is already a de-facto standard in smart homes and lighting, as it overcomes distance limits, either caused by large distances between nodes, or by radiation obstacles like walls.

In case of communication distance issues it is quite easy to insert an additional smart connector with the only function of a repeat message relay.

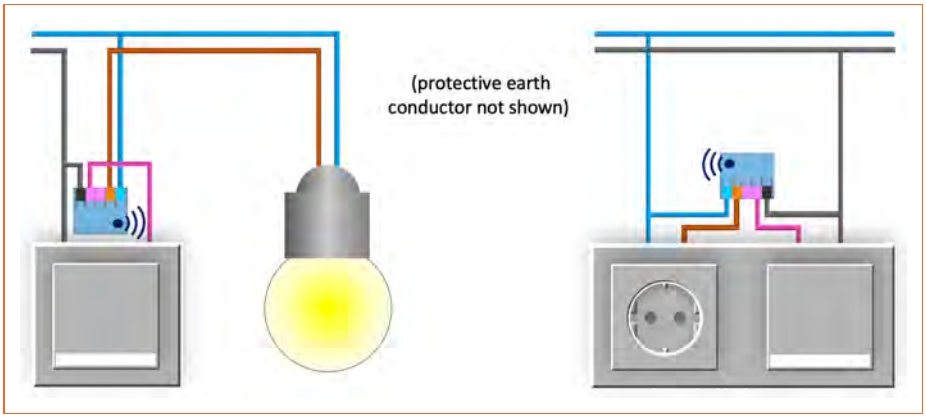

Figure 4: Schematics for hardware upgrade of bedroom with smart connectors - left: door switch upgrade (X), right: upgrade of power outlets for bedside lamps (Y, Z)

Secure Networks

Hacker-proof network security becomes more and more important as the deployment of the internet-of-things progresses. For consumers who worry about connection of their smart home to the internet there is good news: Bluetooth® Mesh is a subsystem on its own, supporting the highest security standards. While Bluetooth Low Energy (BLE) defines security as an option (engineers have the choice to implement BLE-security or not) Bluetooth® Mesh supports security by obligation. This means that all Bluetooth mesh network messages are encrypted and authenticated, and there is no bypass to work around this rule.

Besides this fact Bluetooth® Mesh supports the paradigm of "separation of concerns". There are three different security aspects within a Bluetooth mesh network: Application, network, and device security. They are handled independently of each other and have their own security keys: Application key – securing data relating to specific applications, e.g. lighting or cameras. Network key – applying to all devices belonging to a network, thereby ensuring secure data transfer. Device key – unique for each node – used to add and configure network devices.

Smart Phone/Tablet Compatibility

The importance of the ability of a network device to communicate directly with a smart phone (tablet) has already been mentioned. Communication via a bridge (or hub) is a work around, since it means that multiple bridges have to be installed if smart phone control is desired at each point of the home. Also, a central bridge would be a single point of failure, which is obsolete in case of direct communication.

There is another benefit provided by direct communication with smart phones, which is the proximity function, telling the strength of a received Bluetooth® signal (RSSI) of a device. It allows to authenticate a new device to be provisioned by walking around with the smart phone: If the observed change of the RSSI level meets the expectation then there is no need for an out-of-band information transfer like QR-code reading or NFC transmission. This simplifies the provisioning process essentially, while guaranteeing secure device authentication.

Figure 5: Smart Connectors from Bluenetics

Conclusion

Smart connectors placed in flush-mount boxes offer an easy and cost-efficient way to upgrade existing homes to smart homes. Scenarios like "Kid's room lighting control" or "Partner friendly bedroom light control" are typical scenarios to start a smart home at low entry budget. Bluetooth® Mesh is a future proof open wireless communication standard for smart homes and lighting with strong emphasis on interoperability. Bluetooth® Mesh based smart connectors are widely applicable in home automation, especially if existing installations are intended to be re-used. ■

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Benefits of Personalized Workplaces Solution

An appropriate workplace solution needs a technology that connects devices automatically to each other without limitations of the size of the network since there can be anything from 1,000–4,000 lights in one site. ENSTO recently acquired Mount Kelvin for its advanced lighting controls systems, which takes advantage of Wirepas' technology. Tony Antilla, Head of Workspaces at Ensto, and Mirva Saarijärvi, Head of Marketing & Communications at Wirepas explain the features and how this sophisticated system works.

Quality lighting for large-scale sites needs to work for beyond 1,000 lights in one network. This scale indicates industrial or office set-ups; not home lighting solutions. All the lights installed need to react to the personal needs of people in their workplaces. The electricians that install the lighting have the knowhow to connect physical wires, but they are not equipped to do network planning and configuration, which is a slow and expensive undertaking. Therefore, such a controls system must offer a simple setup while still providing an outstanding user experience.

Meeting the Requirements with the Right Technology

The IoT connectivity network has no device limitation and all the lights – whether it is 1,000 or even 10,000 – connect to each other automatically and form the network itself. There is no need for subnets, as the network can handle thousands of nodes in network without configuration, which makes the installation easy and fast on the site.

All that is needed to be done on-site is to power up the devices and commission them into groups. Groups can be divided e.g. on room level and each group can be controlled with a wireless switch, a sensor (usually motion detector) or with a central lighting control system. Each light can be controlled separately as well, or it can belong to several different groups. Each group can have their individual operational logic. The workspaces lighting control system uses location data of the lights so that it can also be controlled with a mobile application. The application offers a list of the groups closest to the person to be controlled. The motion detectors in the network can also be used to indicate occupancy situation of the rooms: whether or not they are free or in use for e.g. meeting purposes.

How the System Makes This Possible

The system uses a gateway and a wireless node that controls the DALI driver. Discussions with a supplier providing an LED driver that includes the radio component will improve the cost structure even further. For the ones using the workspaces control software there is plenty of available hardware that runs on the drivers that also include a compliant radio component, like the Nordic nRF52. In practice, this means that any device that has nRF52 radio chip, is compliant with the workspaces control software. This makes adding sensors into the network even simpler. All the sensor data can be processed in the lighting control system or exported in to a 3rd party system if needed.

Some examples for supported systems and technologies:

- Control of DALI, EnOcean and Wirepas equipped luminaires
- Gathering data from sensors
- Generating space utilization heat maps based on motion sensor data
- Indoor location of end user mobile devices
- Wireless switches with either Bluetooth beacon or 868 MHz EnOcean signalling
- Mobile application for commissioning and control
- A web application for large-scale commissioning
- An internet-based endpoint for 3rd party system integrations for control and data gathering

Benefiting from an advanced mesh technology

One of the key reasons to go with this type of solution was that building sensor and asset tracking are merging with the lighting systems. This workspace solution, relying on the advanced mesh technology, is currently the only one able to provide a feasible open data transport. So far, all the other lighting control systems are focused on lighting control and not built to carry large quantities of sensor data. Just sensing background light to guide the lighting, will not suffice. The key conclusion is that the need for sensor data is increasing. In the future, there will be more and more sensors to measure in the same system, for example, temperature, humidity, occupancy, and air quality.

A mesh network is a communications architecture where each device in the network called a node can communicate to a number of surrounding nodes. The messages are sent over radio, more specifically a 2.4 GHz radio similar to Bluetooth. To understand discussion on mesh network technology, it is useful to establish common terminology.

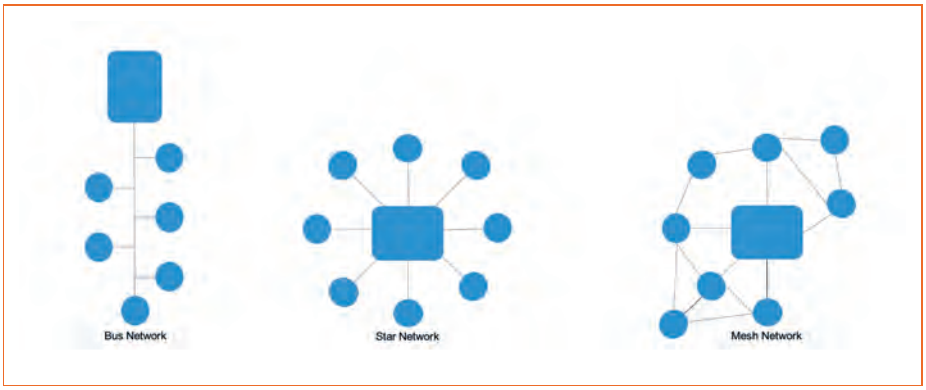

Figure 1: Schematic examples of a linear network, a star network and a mesh network structure

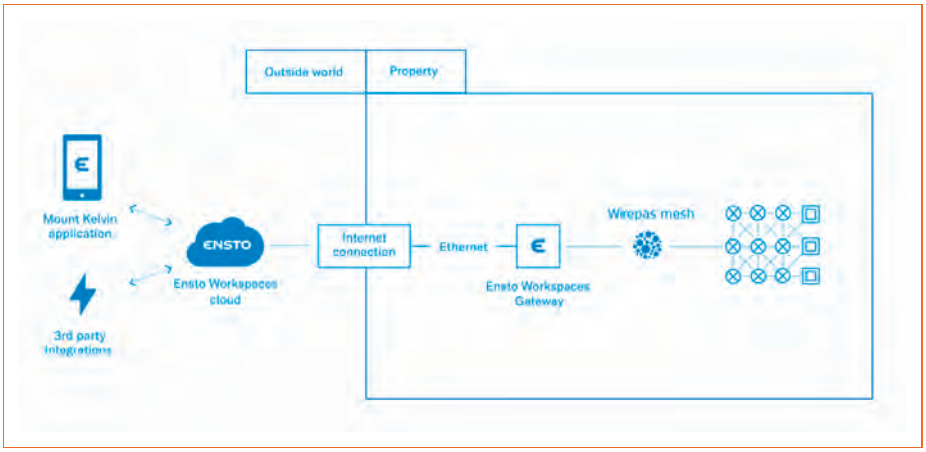

Figure 2: Example of options to connecting to the mesh network solution

Slightly simplified, there are three types of nodes in a workspaces network:

- Routing node, for example a luminaire controller or other mains powered device, which sends and receives their own messages and relays messages from other nodes. A routing node can also behave as a BLE Advertisement scanner (nodes on the right edge of the Mesh network), which listens to Advertisement messages from sensors and switches and rebroadcasts them into the mesh network for other devices to react on
- Non-routing node, a device which only sends and receives data, but does not relay messages from other devices. Battery powered sensors would commonly fall into this category
- Sink, a device which can route messages in the network as well as relay them to the Internet. The Ensto Workspaces gateway falls into this category

In addition to full-fledged members of the network, two additional types of devices can utilize the network:

- BLE advertising broadcasters, such as the wireless push buttons. The routing nodes in the network will listen to broadcasts from the buttons and relay their message to relevant parties inside the network (more information on this in the chapter Reliability and Security)
- BLE beacon listeners, devices that only listen to broadcasts made by the surrounding nodes. The indoor positioning system of the app uses this approach to find the room the user is in.

Most luminaires do not natively include the hardware or software necessary to communicate wirelessly with each other. To that end, it is important to work with established luminaire driver manufacturers to include the necessary communications technology either integrated into the driver or as an add-on module. Smooth transactions in lighting are also a key factor. The human eye can detect any delay beyond a quarter of a second. The protocol is synchronized to minimize latencies but also to provide information of the message travel time allowing the synchronization of the lighting control. Due to the nature of the mesh technology itself, the latency depends on how many devices the messages pass through, aka the number of hops.

Design Considerations for this Wireless Mesh Network

Building electrical design

The building electrical design is very simple. The luminaires only need power, the driver will supply power to the control module and any attached sensors. If standalone presence sensors are used, they will only need power cables.

Very little consideration needs to be given to the placement of end devices. The range of a single node is 5–10 meters in open space. As the luminaires are normally placed every 2–4 meters, the communications network is automatically deployed at an optimal density in almost all cases. In the event of a gap in the network, an additional node can simply be added to bridge the gap in the network. This can also be done after the fact, as the node only needs electricity to operate and commissioning can be done by anyone – the only requirements are a mobile phone with the app. Placement of buttons in this installation is extremely easy. In practice, a push button can be placed anywhere where luminaires or other routing nodes are present, in practice this means anywhere in the building. As the switches are wireless and battery free, the control locations do not need to be decided in advance, the users of the building can be supplied with switches to mount where they wish. We do recommend that when commissioned and taken into use the switches are also attached to a surface with screws (when an installation enclosure is available) or the supplied adhesive pads; practice has demonstrated that unmounted switches can go missing.

The switches communicate with the network via Bluetooth Low Energy advertising messages. To facilitate transferring these messages over longer distances in the network at least one routing node in proximity to the switch needs to have the BLE Advertising listener enabled. This feature can be enabled on any routing node from the app and does not impose a design limitation, but it is useful to be aware of this feature for commissioning. Enabling the advertising listening on every routing node is not advised as this results in multiple duplicate messages being introduced to the network and can cause network congestion or other undesired effects.

Direction	Port	Protocol	Purpose
Outbound	443	TCP	HTTPS to cloud backend, system updates
Outbound	29648	TCP	Logging service for maintenance
Outbound	123	UDP	NTP time synchronization
Outbound	53	UDP	Domain Name Service

Table 1: Firewall settings for open ports to guarantee operation

The solution also introduces very few limitations on sensor placement. Similarly to switches, sensors can be placed anywhere:

Gateway placement

The gateway units can likewise be placed to a WIFI access point. Like a WIFI access point, the only requirements are access to the Internet via Ethernet and mains power. Optimally, the gateway should be placed in the ceiling in an open area with few concrete walls and a large number of routing nodes (such as luminaires) surrounding it. Generally speaking, high node density is a good thing for the performance of this mesh network. High density offers the network the opportunity to send messages over multiple routes so no route gets congested. Having a good device density is particularly important in the network area surrounding a gateway acting as a network sink. All devices will occasionally report their status to the cloud. All of these messages must pass through a sink to get to the Internet.

Figure 3a shows a bad example: the only sink node in the network is separated from the rest of the nodes and individual links in the network become overloaded (marked red in the image). Notably, the network connection between the sink and cloud is not an issue as the messages being passed are very small. Another easy error is forming a network which introduces islands with no sink (**Figure** 3b). In this case, the gateway is correctly placed in a central location, but a narrow network corridor connects two larger groups of nodes. The correct solution to an issue like this is to introduce a network sink in the area on the left as well. **Figure** 3c shows a better solution, where the gateway has been moved to a more central location, distributing the load to multiple nodes.

All in all, the system imposes very few design limitations on building electrification and infrastructure. Even gateways are comparatively easy to introduce after the fact (due to them only requiring power and Internet connectivity), should oversights in the design phase be discovered later.

Network requirements

All Ensto Workspaces gateway units require connectivity to the network. In a typical network no network changes are necessary, but if a firewall with outbound communications restrictions is present, the following ports (**Table** 1) must be open.

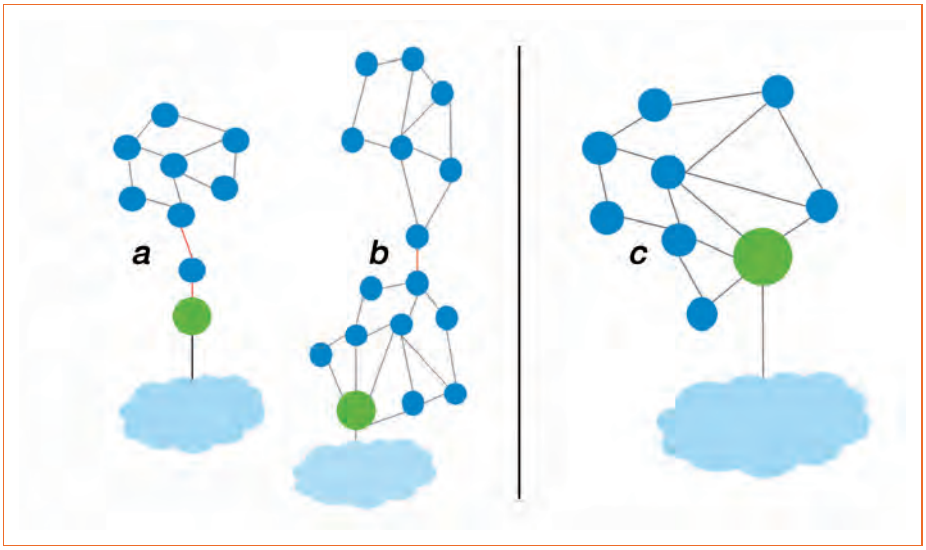

Figure 3: A bad solution for the implementation of the sink node (a) and a bad solution for the mesh design (b) versus a better solution (c) for both

Integration, Compatibility and Reliability as Additional Benefits

Several ways of integrating third party components and service are available. This section is roughly grouped by application. The preferred method of integration is always to use the Cloud API.

DALI

A variant of the gateway unit is available which can act as a Dali controller. The unit can be expanded to support up to 4 DALI universes. The integration allows use of most DALI luminaires and selected DALI sensors as part of the system while 3rd party DALI controllers are not supported.

Web apps, mobile apps, IP based systems and AV systems

An API (Application Programming Interface) is accessible over the Internet. The documentation is available for everyone [1]. The API is built around industry standard tools such as REST, JSON and Websockets. In practice, this means that building an integration does not require specific knowledge about building automation systems, mesh networks, proprietary programming tools or similar areas of rare expertise; anyone with basic web programming knowledge should be able to build an integration. This has also been tried in practice, almost every week we have a new programmer write a small user interface against the API. Most people can complete the task in a matter of hours.

Web and mobile apps

Integrating web and mobile apps is effectively trivial with a concise API documentation to get started.

AV systems

Audio and video control systems often used in meeting rooms are a common integration request. To integrate AV servers, the following should be kept in mind:

- The AV system network has to allow outgoing Internet traffic (incoming traffic is not required)
- The AV system to be integrated should have support for the following
  - HTTPS / SSL encrypted HTTP traffic
  - A parser for JSON messages
  - Support for websockets

About reliability and security

As it is a wireless and internet connected solution, special attention has been given to issues related to reliability and security of the system. Briefly, a few principles have been followed in all aspects of the system:

- Encryption of communication – wireless and wired communications are secured against eavesdropping and message injection with strong encryption
- No single point of failure for critical features
- Updateable: Any connected device must be updated occasionally to remain protected against new threats

In the operation of any building, reliable lighting controls are key. This means the failure of a single device should not render the whole system inoperable. In some systems a central gateway is responsible for all logic. An example could be deciding which luminaires to turn on when a wall switch is pressed. In this sort of architecture, failure of the central component will lead to all luminaire controls becoming inoperative. In this system, all luminaires are aware of which button presses they should react to, so the light switches will work regardless of the gateway. Should all gateways fail, the user will not be able to use their mobile app to configure or control the system.

The system can also be served by multiple gateways, should one gateway be removed (for example due to a circuit breaker tripping), other gateways in the system will assume its responsibilities. The simultaneous failure of multiple gateways is extremely improbable. Communication between the gateway, cloud backend and mobile app are secured with industry standard SSL encryption, similar to common practice in the finance industry for mobile banking. Inside the wireless mesh network, the network is secured with a pre-shared network key, which is used to secure messages in the network. The initial messaging between the Mesh network and a wireless switch can also be optionally encrypted (this option can be enabled from the app).

Conclusions — Why this Technology was Chosen

It is a trend that all lighting is going wireless but until now the lighting control systems modules haven't been able to meet the cost point, allowing to take it where it needs to go. The answers on the challenging requirements for the low cost-point were convincing.

These are:

- A patented routing algorithm
- A mesh solution that uses 40 channels of the BLE radio and chooses the channel dynamically between two devices
- Devices that have dynamic transmission power control that always use the minimum transmit power between devices. This also allows for the mesh to minimize the interference to other wireless devices and networks, a.k.a being neighbour friendly.

In more detail this means that a message doesn't get sent to all the devices in the network but through an optimized route through the devices and the routing happens dynamically reacting to environment. The mesh adjusts the routes according to changing circumstances, and in a network of thousands of sensors, it is possible to add additional gateway devices into the same network, without creating subnets, to handle the increased sensor data load.

If interference is detected on the channel, for example from WiFi devices, the devices automatically change their channel. This channel change does not impact any other devices in the network; it only affects the devices that have changed channel. Typically, in any building, there are several separate WiFi's using different 2.4 GHz channels. This forces the network to be able to dynamically select the channel according to the WiFi interference tolerance even at room level, independently from the other devices in the network.

All these facts allow special features and guarantee future proofness at the same time – a no-brainer. ■

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[1] https://mountkelvin.github.io/api

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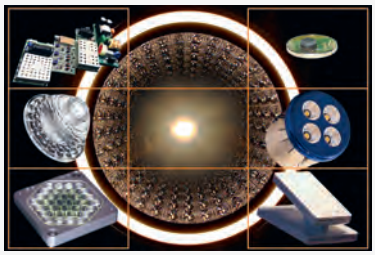

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A system consists of many key components. Eight product images from LpS and LFI were selected for the cover of this LpR issue.

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New Directive in Europe: Flicker of LED Lighting Comes to an End

Over the past 10 years LED lighting has gained in importance. It has also been noticed that the alternating proportion of LED light can be very high compared to incandescent lamps. Many institutions from all over the world have thought about algorithms to measure and evaluate light modulation, taking into account the effect it has on humans. In the meantime, directives have been established in the USA and Europe. But do the directives really have a positive effect on the health of humans and other beings? This article provides insight into this question. ■

Adopting an LED More Suited to Circadian Entrainment and Ocular Health

Since the introduction of LED lights, a lot has been said about risks of blue light for ocular health on the one hand, and the opportunity of circadian entrainment, on the other hand. While a controversial discussion on the first topic is ongoing, the second topic is well accepted. To solve both issues, the author of the article proposes the application of 465–470 nm pumped phosphor converted white LEDs with a content of 86%–92% blue-turquoise light and 8%–14% blue-violet light. He proves the benefit of regulating the circadian entrainment more efficiently, maintaining a high typical efficacy of 150lm/W and good color rendering of CRI 80+ ideally supporting the WELL Building Standard. ■

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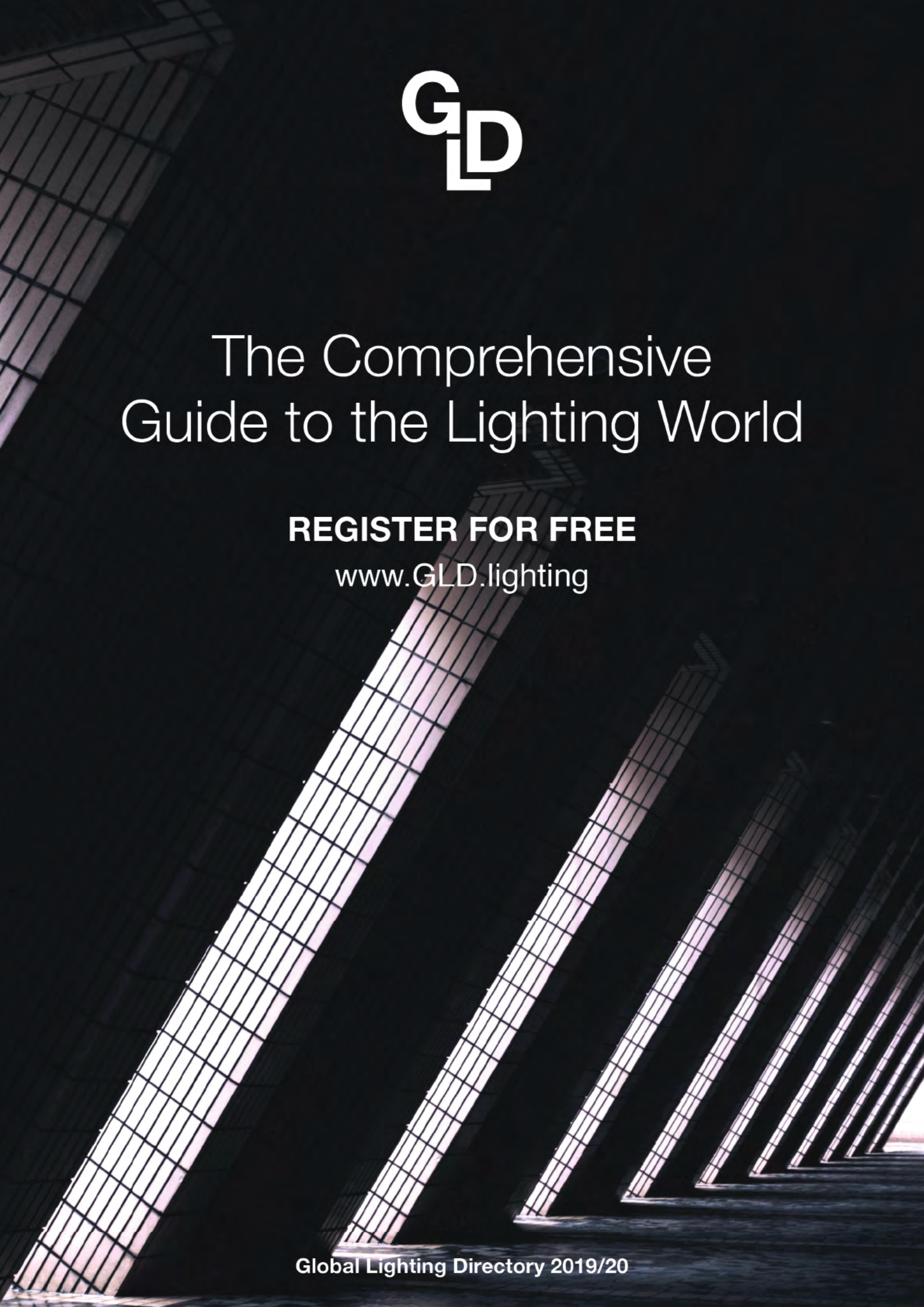
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