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LpR

The Global Information Hub for Lighting Technologies and Design

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Inspiration

This issue of LpR should be classified under the topic of "Inspiration".

One inspiring story is the history and development of Seoul Semiconductor told by Chung-Hoon LEE, the founder and president.

Another article shares the new results of DALI+ with wireless or IP-controlled systems that open new possibilities and chances for unique ecosystems in light.

For more than three years now, Luger Research has been supporting the Repro-Light sustainability project. A comprehensive summary of the results can be found in this release. Let it inspire us to design lighting solutions that are more sustainable.

You'll also find great impulses on the topics of UV-C light sources and materials, thermoplastics, and thermo-simulations. Spectroscopy with various specific LED sources and new approaches of LED drivers round off this issue in the matter of technology ideas.

In his commentary, Andreas Schulz addresses Lighting Enthusiasts. He broaches the interesting topic of the light experience for younger generations.

In any case I hope this issue will be an inspiration to you and beyond that, I hope that you're generally inspired!

Yours Sincerely,

Siegfried Luger

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

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COMMENTARY

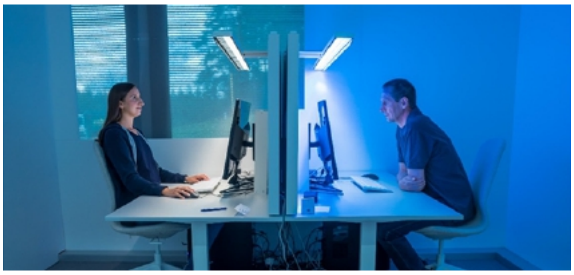
NEWS

LPS DIGITAL

LED BUSINESS – INTERVIEW

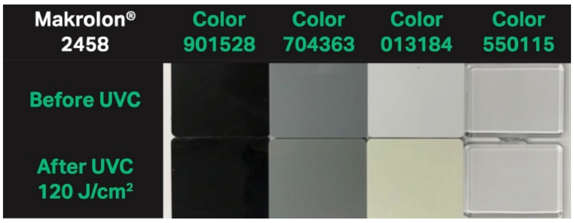
DALI ALLIANCE – INTERVIEW

SUSTAINABILITY



UV-C TECHNOLOGIES

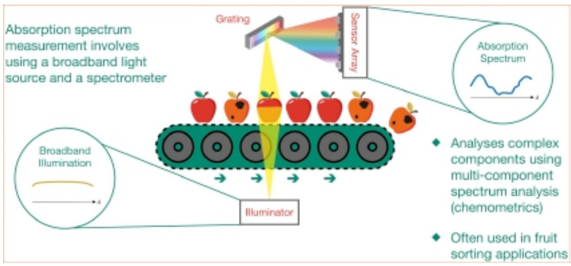
UVC DESIGN – ADVERTORIAL



THERMOPLASTICS

THERMAL SIMULATION

SPECTROSCOPY



LED DRIVER

ADVERTISING INDEX

Andreas SCHULZ

Andreas Schulz has over 30 years experience in lighting design. In 1991, he founded Licht Kunst Licht in Bonn and Berlin simultaneously. The office has published more than 500 book and magazine articles and received numerous internationally known lighting design awards.

Andreas Schulz is a frequent lecturer at professional conferences and university programs. He is also the founding professor for lighting design at the University for Applied Sciences and Arts in Hildesheim, where he is responsible for the education of future lighting designers.

Mr. Schulz is a Lighting and Energy related consultant for the Federal Republic of Germany, a member of the Berlin Lichtbeirat Lighting Advisory Council, and consultant to the building works senator within the German senatorial administrative office for urban development. In 2010, he was appointed Director of IALD and is currently Chair of the IALD Europe Steering Committee.

Dear Lighting Enthusiasts!

We are all part of an enormous paradigm change due to light becoming digital and easier to handle than it was during the last hundred years.

All of our knowledge from visual experience and hard work on the topic of light became history in an amazingly short period of time – and now we rely on this learning process related to increasing knowledge. This development is both good and bad at the same time: it's good because we know what we want and we know what our clients expect regarding light and illumination. But on the other hand it's very challenging – or more precisely, it used to be challenging because it wasn't easy to achieve what we expected regarding color temperature, color rendering and other physical parameters with the new light source LED. Within the last ten years this fact has become history as well; the quality of LEDs has developed amazingly and we never had light sources as good as the ones we use today.

But now there is a new topic we have to consider, as there is a generation of "light consumers" who either grew up with LED light or became interested in lighting when this light source was the only available one. When I talk to my students nowadays, who are predominantly between the ages of 18 to 25, I do recognize that they have a completely different perception of light than users who have a knowledge of previous light sources like halogen lamps, metal halide lamps or fluorescent lamps.

In general, the younger generation likes cold color temperatures better for commercial projects like museums, office buildings and even leisure and retail. Knowing that, some of our clients feel like they're caught between two stools. On the one hand, they want to satisfy people who are used to warmer color temperatures from their life experience and on the other hand, the younger generation who expect a fresher, more neutral environment and therefore colder color temperatures.

These difficulties and ambiguity offer us lighting designers a lot of opportunities instead of causing problems. Our clients are much more open to tunable white design approaches than they were some years ago.

"All of our knowledge from visual experience and hard work on the topic of light became history in an amazingly short period of time – and now we rely on this learning process related to increasing knowledge."

We are currently working on some quite big projects, where we are offering a complete layer of tunable white luminaires for all public spaces. We are very optimistic that these new possibilities will help us to integrate artificial light into daylight-driven areas in a way that wouldn't have been possible until now. And additionally, to emphasize those areas at nighttime for the needs and expectations of the clients, which was also not possible before.

"The quality of LEDs has developed amazingly and we never had light sources as good as the ones we use today."

These fantastic opportunities allow us to point out that we are the witnesses of decades in which digital light will change our general, long term perception very positively.

Viva la luce! ■

A.S.


RÖHM

BUSINESS

New OEM Leader at Signify for Germany, Austria, and Switzerland: Hendrik Theiß Succeeds Franz Jansen

On July 1, Hendrik Theiß took over as head of Signify's OEM business in Germany, Austria, and Switzerland (D/A/CH). He succeeds Franz Jansen, who will end his career after more than thirty-five years of service to Philips, Philips Lighting, and Signify. Hendrik Theiß


Hendrik Theiß

joined Philips in 2007 directly after graduating from high school and completed a dual study program there until 2011. Since then, he has worked through a variety of areas and positions at Philips Lighting and Signify. Until 2018, he worked in the OEM area first as a Key Account Manager and later as an International Key Account Manager and Business Development Manager. In 2018, Theiß moved to the Professional team as Key Account Manager Office. Since 2019, Hendrik Theiß has been Sales Manager in the Office & Industry area and took over the management of the Systems & Services team for the O&I area as part of the reorganization. With the new task, he now returns to his OEM roots.

"Franz Jansen played a key role... in paving the way for the age of networked lighting in the OEM business."

RADA RODRIGUEZ, SIGNIFY MANAGER

Franz Jansen began his career at Philips after completing his studies in 1985 in the semiconductor business of Valvo, then the components division of Philips. Six years later, he moved to Philips Lighting, where he took over the management of the OEM business in D/A/CH shortly afterward in 1993. In addition to international tasks as manager for the UV component business, his regional activities also took him around the world.

"Franz Jansen played a key role in shaping the transformation of the lighting industry and played a decisive role in paving the way for the age of networked lighting in the OEM business. We thank him from the bottom of our hearts for his dedication and commitment over the past 35 years and wish him the best of health and all the best for the coming phase of his life. At the same time, we are very pleased to welcome Hendrik Theiß in his new position. We are sure that he and his team will consistently continue and shape the path they have taken," said Rada Rodriguez, Signify Manager. ■

Marco Steffenmunsberg – New CEO at Regiolux

Since 1 June, Marco Steffenmunsberg has been the new Chief Executive Officer of Regiolux GmbH (www.regiolux.de). The 47-year-old made the transition from the role of Business Unit Manager at RZB Rudolf Zimmermann, Bamberg GmbH to the luminaire specialist for the technical lighting sector based in Königsberg, Bavaria.

With Marco Steffenmunsberg at the helm, Regiolux has gained a proven expert with many years of experience in leading positions within the lighting industry, who also possesses sound management experience within marketing and sales. He succeeds Petra Polster, the long-standing CEO of this successful, medium-sized family business, who is due to retire this year. Marco


Marco Steffenmunsberg

Steffenmunsberg had been with RZB since 2007. At the luminaire manufacturer, the graduate with a Master of Arts (M.A.) in Marketing and Sales Management and a Bachelor of Arts (B.A.) in Business Administration held a number of management positions – including Sales Manager for the Germany North region, Head of Business Development and, most recently, Business Unit Manager. In his new position as CEO of Regiolux, Marco Steffenmunsberg sees himself simultaneously as a guarantor of continuity and a source of impetus and strategic skill for the company's forward-looking development. "I look forward to embracing the challenges that the industry will face stemming from the digitalisation of lighting technology, and to actively shaping the exciting change that this will entail," Marco Steffenmunsberg emphasises. ■

LightingEurope Advocates for All Building Renovations to Include an Upgrade of Lighting Installations

Ourania Georgoutsakou, Secretary General LightingEurope

With its Renovation Wave Initiative (RWI), the European Union (EU) intends to at least double the rate of building renovations in Europe over the next 10 years. In doing so, the European Commission hopes to reignite Europe's economy for a post-pandemic world and ensure that the EU meets its Green Deal climate objectives of reducing net greenhouse gas emissions by at least 55% by 2030 and becoming climate neutral by 2050.

In support of the RWI, the European Commission has published a targeted revision of the Energy Performance of Buildings Directive (EPBD), the EU's main instrument for improving the energy efficiency of its building stock.

"With buildings accounting for 40% of the EU's total energy consumption and 36% of all greenhouse gas emissions, building renovation will play a key role in achieving the Green Deal's goals," says Ourania Georgoutsakou, Secretary General of LightingEurope, the voice of the lighting industry.

The Commission notes that investing in more energy efficient buildings will help create jobs, both in the construction sector and the wider economy, resulting in a net positive impact on GDP and employment. It also acknowledges that energy-efficient renovation can improve comfort and sanitary conditions, making buildings healthier and improving the well-being and productivity of its inhabitants.

"Nearly 34 million Europeans are unable to afford keeping their homes heated," says Frans Timmermans, Executive Vice-President of the European Commission in charge of the EU Green Deal. "We want everyone in Europe to have a home they can light, heat, or cool without breaking the bank – or the planet."

In light of this, LightingEurope sees the revision of the EPBD as an excellent opportunity to accelerate the uptake of innovative, LED-based intelligent lighting systems.

"Considering the important role lighting plays in delivering energy savings, creating safe and quality indoor environments, and spurring economic recovery, LightingEurope believes all building renovations must include an upgrading of the lighting installations," adds Georgoutsakou.

Advocating for the inclusion of lighting systems in the EPBD revision, LightingEurope has issued a number of specific recommendations:

Using LED Lighting in Combination with Controls and Sensors and with a Minimum SRI Level
Lighting accounts for around 20% of the total cost-effective electrical energy savings potential in non-residential buildings. Furthermore, properly designed and well-coordinated lighting systems are one of the most cost-efficient ways of reducing energy consumption and CO2 emissions.

According to a study prepared for the European Commission, LED-based lighting systems could save the EU up to 29 TWh/y of electricity by 2030 and up to 56 TWh/y by 2050. "Clearly, including intelligent lighting systems in the EPBD would significantly increase a building's energy savings and help reduce its greenhouse gas emissions," explains Georgoutsakou.

As such, LightingEurope recommends the use of LED lighting in combination with controls and sensors and with a minimum Smart Readiness Indicator (SRI) level, with the SRI being applied across Europe to maximise its potential for energy savings.

Adding Inspection Requirements
LightingEurope also recommends adding lighting inspection requirements to the EPBD. "A periodic assessment will have to be carried out to ensure the proper functioning of the lighting systems," notes Georgoutsakou.

Important inspection parameters and questions include how the building space is being utilised, whether the lighting system and application are still suitable (i.e., whether the light levels are sufficient to provide good quality lighting), and whether the controls are still optimised for the way the space is used.

Mandatory Minimum Requirements on IEQ
With people spending approximately 90% of their time indoors, there is a growing demand for indoor comfort and wellbeing. LED-based intelligent lighting systems help ensure a more comfortable indoor environment, allowing users to dynamically adapt light to their specific needs. For instance, students in a classroom with bright white lights score 14% higher than students working in a poorly lit one.

"Including lighting systems in the EPBD will help improve the visual comfort, wellbeing, and productivity of building users," says Georgoutsakou. "This is why LightingEurope advocates for the introduction of mandatory minimum requirements on Indoor Environment Quality (IEQ)."

Installing UV-C Disinfection for Safe Indoor Spaces
The current pandemic has reinforced discussions around how to create spaces where individuals can coexist and collaborate with minimal risk to their health. Short wavelength ultraviolet (UV-C) is an established disinfection technology that is proven to be effective in combating micro-organisms and viruses. LightingEurope advocates for the design of safe indoor spaces that includes the installation of UV-C disinfection.

Lighting System Design Process
To reap the full benefits in terms of energy efficiency and Indoor Environmental Quality, the Lighting System Design Process must be followed.

Tying Access to Public Financing to the Inclusion of Lighting Renovation
Including LED-based intelligent lighting systems in the EPBD will also accelerate the uptake of innovative lighting technologies and future investment. This in turn will play an essential role in helping Europe's lighting industry – 80% of which are SMEs – recover from the economic consequences of the pandemic. To help foster this uptake, LightingEurope recommends that access to public financing and subsidies be subject to the fulfilment of certain conditions, such as the inclusion of lighting renovation.

The Benefits are Clear
The energy, health, and economic benefits of quality lighting are clear. "Only by ensuring that there is no renovation without an upgrade of the lighting installation in the EPBD will we ensure that Europe experiences a renovation renaissance – and not a wasted opportunity," concludes Georgoutsakou. ■

DOE Announces New L-Prize for Next Generation LED Lighting

The Lighting Prize (L-Prize) is designed to advance the U.S. clean energy economy for next-generation LED lighting, encouraging innovators and researchers to engage in advanced lighting system development that leads to transformative designs, products, and impact. The L-Prize will reward innovations that move rapidly to improve lighting performance, resulting in energy, carbon, and cost savings for American businesses and consumers.

The first Lighting Prize was awarded by the U.S. Department of Energy (DOE) in 2011, recognizing a high-efficiency LED replacement for the traditional 60-watt A19 incandescent bulb. Today, commercially available LED lights are competitive with all other lighting technologies, but the full technical and application potential of solid-state lighting (SSL) still far exceeds today's products. Advanced interoperable lighting systems have the potential to better manage lighting energy use, integrate with other building systems, streamline maintenance and operations, and even respond to electric grid signals, increasing the value and resiliency of buildings. The L-Prize, a successor to the first Lighting

Prize, seeks to unlock the additional potential to combine high-luminaire efficacy with exceptional lighting quality, data-driven control and functionality, innovative design, construction, and grid flexibility for the future of illumination in commercial and institutional buildings. In addition to these technical innovations, the L-Prize also invites innovation for diversity, equity, and inclusion in how systems are designed, produced, deployed, or installed.

The L-Prize targets commercial sector lighting, which accounts for 37% of national lighting energy use, and encourages lighting innovators to design lighting systems with breakthrough energy efficiency, quality, functionality, and sustainability. A full realization of SSL technology potential envisions LED lighting products manufactured with significant domestic materials, while demonstrating exceptional energy efficiency, data connectivity, seamless lighting control, excellent visual quality, and design for recycling and remanufacturing.

DOE's Building Technologies Office invites lighting innovators to participate in this new competition to bring tomorrow's lighting into today. ■

Signify Expands Offering for Smart Cities by Acquiring Telensa

Signify (Euronext: LIGHT), the world leader in lighting, announced that it acquired Telensa Holdings Ltd, a UK-based expert in wireless monitoring and control systems for smart cities. With Telensa, Signify adds a

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Zhaga Summit

Sustainable Lighting for Smart Cities and Buildings

The Zhaga Consortium is hosting this online event with speakers from national authorities, cities, industry association, lighting design and manufacturing.

The target audience are manufacturers of lighting products and specifiers, users and investors of smart city and building lighting installations.

THE PROGRAM:

- ***sheds light*** **on the regulatory framework** around circularity and new visions in lighting design,
- ***discusses*** **pioneering use cases** from cities, national authorities and manufacturers, and
- ***explains the role of Zhaga*** in support of the trend towards sustainable lighting.

Find out more at:
zhagastandard.org/zhaga-summit

narrow-band and TALQ-compliant solution to its feature-rich, open and secured systems. This will enable Signify to service a broader group of customers, by making smart city infrastructure affordable to cities utilizing the unlicensed radio space. Telensa will continue to sell its systems under its own brand name.

The acquisition supports Signify's strategic priority to grow in professional systems and services. Together, Signify and Telensa will be able to service the many towns & cities around the world which want to reap the benefits of connected lighting in a cost-efficient way, and bring them into a smart city central management system.

"We are very excited to welcome Telensa as part of Signify. With its talented team and proven track record, we are adding a well-established technology and competitive offering to fuel the uptake of solutions for smart cities around the world," said Harsh Chitale, Division Leader Digital Solutions at Signify

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Telensa, headquartered in Cambridge, UK, was founded in 2005 and employs 58 people. The company's preliminary sales amounted to approximately GBP 11 million for the year ending March 2021. To date, Telensa sold approximately 100 networks connecting over 2 million light points in more than 400 cities worldwide. Recent projects in the US, Brazil, Hong Kong, UAE, Australia and New Zealand have shown the global reach of Telensa's activities. ■

Acuity Brands Acquires the ams OSRAM Digital Systems Business in North America

Acuity Brands, Inc. (NYSE: AYI) ("Acuity") a leading industrial technology company announced it has signed a definitive agreement to purchase ams OSRAM's North American Digital Systems (DS) business. Acuity's ownership of ams OSRAM's North American DS business will bring a strategic fit and perspective to customers and associates, and a growth strategy for the business. Acuity expects the transaction to close during the summer of 2021.

The ams OSRAM North American DS business develops and manufactures lighting components including LED drivers, LED light engines, electronic ballasts, and certain connected components. The ams OSRAM Digital Systems business is one of the largest LED lighting driver companies in North America. LED drivers are a crucial component of the vast majority of luminaires and enable embedded smart technologies to make lighting and controls more accessible and reliable. The acquisition of the ams OSRAM North American DS business and addition of their team of associates will expand Acuity's capabilities and its advanced LED driver portfolio, which currently includes the eldoLED® driver and IOTA® emergency driver brands. "We look forward to serving ams

OSRAM's North American DS business customers and providing our industry with the most advanced portfolio of integrated digitally connected luminaire technology and LED drivers," said Trevor Palmer, President, Acuity Brands Lighting and Controls business. "We are excited to welcome the North American DS team to Acuity as we lead the industry's shift to embedded lighting technology in communities where people live, learn, work and play."

"Acuity is an industry leader with a long history of bringing innovative technology, products, and services to market. We are excited about the opportunities for our employees, customers, and business partners," said Wilhelm Nehring, CEO ams OSRAM Digital Systems business.

"We lead the industry's shift to embedded lighting technology in communities where people live, learn, work and play."

TREVOR PALMER, PRESIDENT, ACUITY BRANDS LIGHTING AND CONTROLS BUSINESS

Acuity's acquisition of ams OSRAM's North American DS business includes approximately 1,100 associates in the U.S., Canada, and Mexico. The transaction is subject to the satisfaction of certain customary closing conditions. Until close, the companies will continue to operate independently. The parties have agreed not to disclose financial details or other terms of the transaction. ■

Renesas and Dialog Semiconductor to Join Forces to Advance Global Leadership in Embedded Solutions

Renesas Electronics Corporation ("Renesas", TSE: 6723), a supplier of advanced semiconductor solutions, and Dialog Semiconductor Plc ("Dialog", XETRA:DLG), a provider of power management, charging, AC/DC power conversion, Wi-Fi and Bluetooth® low energy (BLE) technology, announced they have reached an agreement on the terms of a recommended all-cash acquisition by Renesas of the entire issued and to be issued share capital of Dialog (the "Acquisition") for EUR 67.50 per share, representing a total equity value of approximately EUR 4.9 billion (approximately 615.7 billion yen).

- Acquisition of Dialog's low-power technologies and connectivity expertise centered around its mixed-signal integrated circuits (ICs) adds complementary product lines, strengthening Renesas' global footprint across large, high-growth markets in the IoT, industrial and automotive fields,
- Expected to result in incremental revenue growth of approximately 200 million USD (non-GAAP operating income, approximately 21.0 billion yen) from cross selling and access to fast-growing industries alongside continued innovation of solution offerings; expects cost savings from operational efficiencies to result in a financial impact of approximately 125 million USD (non-GAAP operating income per year on a run rate basis, approximately 13.1 billion yen),
- EUR 67.50 per share in cash to be paid for all Dialog outstanding shares (on a fully diluted basis), equivalent to a total equity value of approximately EUR 4.9 billion,
- Expected to be accretive to Renesas' non-GAAP gross margin, and EBITDA after closing and to close by the end of 2021.

Dialog is an innovative provider of highly-integrated and power-efficient mixed-signal ICs for a broad array of customers within IoT, consumer electronics and high-growth segments of automotive and industrial end-markets. Centered around its low-power and mixed-signal expertise, Dialog brings a wide range of product offerings including battery and power management, power conversion, configurable mixed-signal (CMIC), LED drivers, custom mixed-signal ICs (ASICs), and automotive power management ICs (PMICs), wireless charging technology, and more. Dialog also offers broad and differentiated BLE, WiFi and audio system-on-chips (SoCs) that deliver advanced connectivity for a wide range of applications; from smart home/building automation, wearables, to connected medical. All these systems complement and expand Renesas' leadership portfolio in delivering comprehensive solutions to improve performance and efficiency in high-computing electronic systems.

"The transaction we announced represents our next important step in catapulting Renesas' growth plan to achieve substantial strategic and financial benefits, following our previous acquisitions," said Hidetoshi Shibata, President and CEO of Renesas. "Dialog has a strong culture of innovation along with excellent customer relationships and serves fast growing areas including IoT, industrial and automotive. By bringing Dialog's talented team and expertise into Renesas, together, we will accelerate innovation for customers and create sustainable value for our shareholders."

"For several years, we have successfully executed on a diversification strategy that positions Dialog for high-growth," said Dr. Jalal Bagherli, CEO of Dialog. "We have built a strong foundation of high-performance analog and power efficient mixed-signal expertise, extended our product portfolio and applied our technologies into markets including 5G, wearables, automotive, smart home, connected medical and industrial IoT. This compelling platform – combined with Renesas' leading embedded compute, analog and power portfolio – creates even greater growth opportunities in today's increasingly connected world. The Dialog team is excited to join forces with Renesas. The combined company will be in an even stronger position to provide innovative products for these markets, building on Renesas' extensive sales, distribution and customer support capabilities." ■

Glamox Acquires Luminell

Glamox AS has entered into an agreement to acquire 100% of the shares in the Norwegian company Luminell Group AS. Established in 2010, Luminell has achieved a strong position as a high-quality developer and supplier of floodlights, searchlights and lighting controls in the marine and offshore lighting market. Luminell is known for being user-focused and developing excellent lighting solutions for demanding applications.

"Together, Luminell and Glamox will have a leading product offering in the global marine and offshore market for all vessel sizes," says Glamox CEO Rune Marthinussen. "The merging and strengthening of Luminell and Glamox product development capabilities will amplify our technological ambitions and benefit our customers."

"We are two companies with dedicated employees who have both achieved a significant position in the global market for maritime and offshore lighting," says CEO Bente Storhaug Dahl of Luminell. "Together, Glamox and Luminell will offer more complete solutions to all our customers and stand stronger together in the development of future solutions."

"Our goal is for our customers to choose Luminell and Glamox because we have the best lighting solutions that allow our users to carry out their missions smoothly and efficiently, whether it's a critical rescue or a risky crane operation. Together we will be able to develop this to new heights," says Luminell's Founder and Chief Technology Officer, David Fink. Luminell will be part of the

Glamox Global Marine and Offshore Division, led by Frode Scott Nilsen. ■

Fagerhult Group Acquires Seneco

To strengthen the connectivity offering for outdoor environments, the Fagerhult Group has acquired the remaining 80% of shares in Seneco A/S. Seneco is a Danish lighting connectivity company founded in 2010. The system consists of a full wireless product range for outdoor luminaires, connected to the system is also an online portal for remote monitoring and integration to other installations. Besides creating more safe outdoor environments, the system leads to significant energy savings and lower maintenance costs. Most of Seneco's installations are today found in Denmark and adjacent European markets. "In 2017 we acquired 20% of Seneco and we have since seen a good adoption of the technology across our brands. As a leading European outdoor lighting provider this acquisition helps us to further strengthen our offering and increase our competence level, which is a key strategic initiative for us. I am very happy to welcome the Seneco team to Fagerhult Group," says Bodil Sonesson, CEO Fagerhult Group. The process was completed April 8th 2021.

SOLUTIONS

NICHIA Introduces High-Power 1800K LED as Industry's Only True Alternative to High Pressure Sodium Lamps

NICHIA, the world's largest LED manufacturer and inventor of the high-brightness blue and white LEDs, announces its 219F series of high-power LEDs, uniquely positioned as a true alternative to High Pressure Sodium lamps (hereinafter abbreviated as HPS). Global efforts to phase-out the use of HPS continue to be met with a resistance to using white LED replacements. Due to this lack of a viable and sustainable alternative, HPS have remained exempt from the list of banned products under the Minamata Convention on Mercury, meaning HPS remains ubiquitous. With the introduction of the 219F, NICHIA becomes the first LED manufacturer to provide that alternative. NVSW219F eradicates mercury but increases efficiency and lifetime, with a low (1800K) correlated color temperature output that works with HPS to retain the element of 'nostalgic landscape' lighting, making it a true alternative.

Existing LED solutions fail to meet the light profile demanded by applications currently serviced by HPS. This typically requires a light level with a low correlated color temperature (CCT) of 1800K to recreate the 'nostalgic landscape' effect typified by HPS. NICHIA has developed the 219F at 1800K/CRI 70 to address this, with technology that can meet the CCT and color rendering index (Ra) required for street lighting applications and lighting for parks and other outdoor areas.

NICHIA's newest technology brings plenty of benefits in addition to the color matching with HPS. The color rendering index (CRI) of the 219F is higher than HPS, increasing it from less than 5, by NICHIA measurement, to over 70, which enhances the natural colors of a city vs. the monotone rendering with HPS. The ability to generate a true color landscape delivers comfortable and bright lighting while retaining nostalgic and/or elegant atmosphere. This is also conducive to security applications as it helps to distinguish the color of clothes, cars and buildings under the street lighting. Also, LEDs allow for instantaneous on/off and output modulation or dimming controls. Enabling "smart lighting" will lead to energy savings. For example, in areas of low pedestrian traffic, LEDs, controls and sensors can allow for intermediate light levels with instant-on or full brightness when motion is detected. This is not possible to achieve by HPS, and is a significant advantage that LED lighting can offer. Lower glare, with a subsequently reduced impact on people, flora and fauna, less blue-light emissions, reduced light pollution, these are also merit driven by 219F/1800K/CRI 70. Needless to say, LEDs help to achieve mercury-free replacement and offer longer lifetime. The 219F can deliver up to 60,000 hours of operation, over twice the average of HPS (24,000 hours).

"People like the visual effect provided by HPS, creating what we call the 'nostalgic landscape'. Existing LED technology finds it hard to replicate this. The measured CCT of HPS is 1800K, which only NICHIA has successfully recreated after various color matching tests," said Yuji Itsuki, General Manager of Marketing, NICHIA.

"The 219F is the only LED available today that can accurately match the CCT of HPS. This ability to blend LED and HPS without creating harsh variations is what really makes it the first in the industry to provide a true alternative," said Yuji Itsuki, General Manager of Marketing at NICHIA.

NICHIA offers 1800K as an excellent recommendation for HPS replacement but provides other lower CCT options as well. With four lower CCT levels covering 2500K, 2200K, 2000K and 1800K, the 219F series meets all market requirements. To recreate the nostalgic landscape effect created by HPS, customers can select the 1800K model. Customers prioritizing power efficiency can select the 2500K model. To meet the guidelines of the Design Lights Consortium (DLC®), customers can select the 2200K model. If customers give an importance on HPS catalogue value, they can select 2000K.

"People like the visual effect provided by HPS, creating what we call the 'nostalgic landscape'."

YUJI ITSUKI, GENERAL MANAGER OF MARKETING AT NICHIA.

NICHIA's 219F series will be available in September. For additional information, customers can contact their local NICHIA office. ■

New Mid-Power LED Enables Luminaires to Meet Latest DLC V5.1 Premium and EU's ErP Ecodesign Requirements to Accommodate Evolving Needs of the Lighting Industry

Samsung Electronics Co., Ltd., a world leader in advanced digital component solutions, introduced the LM301B EVO, a new mid-power LED package that has been designed to set the pace in light efficacy and color quality for indoor and industrial applications.

Global regulations and standards for lighting, once centered on light efficacy, are becoming more comprehensive to include strict criteria for energy efficiency and color quality. The European Union's energy labels for light sources (Energy-related Products Directive; ErP) have been revised to become more stringent, and the Design Lights Consortium (DLC) — a non-profit organization for lighting standards in the U.S. and Canada — has added an index for color quality while requiring the same high efficacy level.

The LM301B EVO helps to meet the rigorous lighting standards on both energy efficiency and color quality. Built upon Samsung's proprietary flip-chip design, the LED package features the industry's highest efficacy of 235 lumens per watt (lm/W), by applying a new reflective material inside the packaging mold and improving phosphor conversion efficiency. Samsung also fine-tuned the red spectrum in the LED's phosphor mix to enable superior color quality, especially with the red hues which are usually more difficult to render accurately.

"Our new LM301B EVO offers an unrivaled mix of light efficacy and color rendering that aligns nicely with the changing landscape of LED lighting standards," said Un Soo Kim, senior vice president of the LED Business Team at Samsung Electronics. "Samsung will continue to provide value-added LED light sources through technological innovation, as we push hard to exceed energy standards across the globe."

When using the package, luminaire manufacturers can create lamps that qualify for the ErP Directive's Grade A certification and meet the DLC's latest V5.1 Premium requirements while achieving industry-leading efficacy.

Based on the industry-standard 3030 platform, the LM301B EVO can be easily integrated into existing and newly designed fixtures for general and premium luminaires.

The LM301B EVO is now in production and available in color temperatures ranging from 2,700K to 6,500K. To facilitate adoption into existing markets, the package will also be available in two lighting modules — the Q-series EVO optimized for indoor lighting at offices and schools, and the H inFlux EVO for high–ceiling applications including factories and warehouses. ■

LUXEON 5050 Offers Advanced Options for the Horticulture Industry

Lumileds, a global leader in innovative lighting solutions and the originator of the 5050 LED, is again improving LUXEON 5050 Round performance and is characterizing the LED for use in the horticulture industry. For illumination applications, 70 CRI lumen performance increases by as much as 5lm. In the case of a minimum 15,000 lumen streetlight, this equates to a 10% reduction in LEDs and significant cost savings.

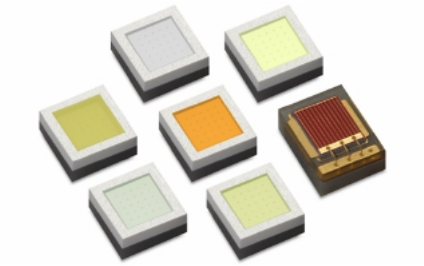
According to Product and Marketing Manager Mei Yi, "High efficacy, high light output and corrosion resistance that outperforms others are key to the preference for LUXEON 5050. We've continued to invest in this LED platform, and as a result, our customers can continue to optimize their solutions and support sustainability while improving lighting."

The use of white light in horticulture applications continues to increase. The combination of efficacy, light output, and corrosion robustness makes LUXEON 5050 a perfect fit in this segment. These LEDs now deliver top-rated □mol/J and PPF (□mol/s) performance and long lifetime with CCTs ranging from 2200K to 6500K and CRIs of 70, 80, and 90 to better support the horticulture industry. Further, LUXEON 5050 Round offers hot-color targeting to ensure that the LEDs are within color target at application conditions of 85°C.

"High efficacy, high light output and corrosion resistance that outperforms others are key to the preference for LUXEON 5050," said Product and Marketing Manager Mei Yi.

All LUXEON 5050 products are available today through Lumileds distribution network. ■

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



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

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

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

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

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

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

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

J Series® 2835 G Class Mid Power LEDs

J Series 2835 G Class LEDs combine high efficacy and superior value in an industry-standard package. Optimized for both horticulture and general illumination applications, these LEDs are valued for their high efficacy and uniform appearance in applications such as downlights, troffers, panels and grow lights or for lighting applications where color quality is critical. J Series 2835 G Class LEDs are smaller, less expensive, better performing and higher efficacy than 3030s.

About Cree LED
Our name has changed, but our commitment to superior LED technology, reliability, innovation, support, and service remains steadfast. The same teams with years of Cree LED experience are newly energized to help our customers improve their LED-based products and develop new applications. Our global distribution channels and sales team remain in force. Operations continue at full speed. Our new name embodies our relentless focus on advancing LED technology. ■

Luminus Releases Hospitality COB Series for Hotels and Restaurants

Luminus Devices has announced its new Hospitality COB series featuring high color rendering, precise chromaticity control and

Warm CCTs. With LES sizes ranging from 6mm to 22mm, and lumen output from 500 to 5000 lumens, the Luminus Hospitality COB series is the smart choice for beautiful, warm light with excellent color rendering and 2 step SDCM color control standard.

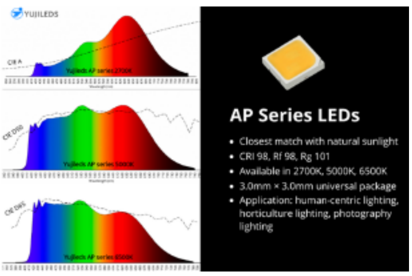
As LEDs have been adopted into indoor illumination applications over the past decade, the industry has reached impressive cost and energy efficiency goals, but for Luminus, the focus has always been on taking the quality of light to new heights. Luminus now further establishes their leadership position with the Hospitality COB Series, with high color rendering, precise chromaticity control, and warm CCTs specifically designed to deliver comfortable lighting scenes in hotels, restaurants, and other applications where warm, quality of light is essential.

What makes the Hospitality COB Series

different from other warm light sources? Luminus engineers teamed up with global hospitality lighting customers to identify unique "xy chromaticity" targets just slightly below the black body locus (BBL) where the warm tint provides a comfortable environment for humans without any "greenish" tint which might be present with typical industry standard lights. Until now, the lighting industry has largely followed the CCT chromaticity "bins" defined by ANSI which are centered on the BBL at nominal, warm CCTs of 2700K, 3000K, and 3500K. This means that half of the light sources will be above the BBL and half below, and those above will lean toward a greenish tint, which is extremely unattractive, especially on human skin. The 4000K ANSI color space is even centered slightly above the BBL, which further raises the possibility of your standard LEDs from other suppliers producing that undesirable green tint. The Luminus Hospitality COB Series also leverages unique phosphor and chip combinations to deliver 90 or 95 CRI minimum, high R9 values, and industry-leading TM-30-15 & TM-30-18 specifications.

"While this COB series was created for the hospitality industry, we're finding that the 2-step color control, excellent color rendering, and attractive warm tones on human skin also appeal to lighting designers for retail shops and other public spaces," said David DAVITO, Sr. Global COB Marketing Director. ■

YUJILEDS Introduces AP Series Full-Spectrum LEDs



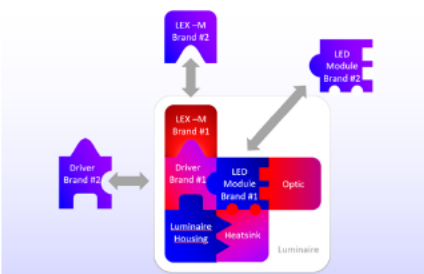
Full-spectrum technology enters a new era. YUJILEDS releases the AP Series full spectrum LEDs powered by the company's advanced phosphor and packaging technologies. The new product features an ultra-homogeneous spectrum achieving the closest match with the spectrum of natural sunlight in the industry.

This full-spectrum technology is a significant development in LED lighting as YUJILEDS focuses on high-performance, value-added LED technologies and solutions.

98% spectral similarity to natural light
With spectrum coverage from 400nm to 730nm, the AP Series LEDs come in three standard spectra of 2700K, 5000K, and 6500K corresponding to the CIE illuminants of A, D50, and D65, respectively. Compared to these standards, the AP spectra achieve 98% similarity within one compact package (3030), which is unprecedented for all LEDs in the market. The spectra of YUJILEDS AP Series LEDs are smooth and continuous. There are no longer strong peaks or obvious gaps like a regular LED.

Industry-leading and ultra-stable color rendition
YUJILEDS AP Series LEDs deliver satisfying results in various metrics. For TM-30, the most comprehensive and convincing method for color rendition, the AP Series gives the Rf 98, Rg 101, and 99 color fidelities above 95 and average 98; For CRI, the product achieves R1-R15 values above 90 and average 97, and is stable on different color temperatures. Halogen and daylight are the most frequently used color temperatures in the broadcasting lighting environments, with the superb homogeneous spectrum, the AP 2700K (TLCI 96) and 6500K (TLCI 99) are not compromised in the quality to ensure the correct colors on cameras. ■

Zhaga: Standardizing Interfaces, Enabling Interoperability



Lighting must become both connected and serviceable to unlock IoT related business opportunities, enable the circular economy, and meet regulatory expectations. But doing so requires standardized interfaces that support interoperable components – which is where Zhaga comes in.

"Zhaga, the global lighting industry organization, puts the spotlight on interoperability," says Dee Denteneer, Secretary General of the Zhaga Consortium. "Our mission is to specify the electrical, mechanical, optical, thermal, and communication interfaces for the interoperable components used in LED luminaires."

According to Zhaga, a luminaire component is interoperable when it can be combined with (an)other interoperable component(s) and function as specified in the component datasheet. "Interoperability requires that components match on all aspects of each relevant component interface," adds Denteneer.

To illustrate, Denteneer points to replacing an LED module with a more efficient LED module. "The new LED module is considered interoperable if it fits into the luminaire and can function according to its datasheet," he explains.

However, such interoperability is only possible when the proper interface specifications are in place. "At the most basic level, a specification supports interoperability when all the compliant components of a first type are interoperable with all the compliant components of a second type," says Reinhard Lecheler, Chair of the Zhaga Steering Committee. "In more advanced cases, the specification defines several profiles, with the interoperability of compliant components limited to the defined profiles."

In all cases, the specification never interferes with safety and other regulatory requirements. Zhaga develops interface specifications, known as Books, that define the necessary conditions for interoperability and serve as the standard for the lighting industry. For example, Book 18 specifies the smart interface for outdoor luminaires, while the smart interface for indoor luminaires specified in Book 20 allows luminaires to be interoperable with sensing and communication modules in indoor applications.

"These interface standards create ecosystems of interoperable components, and the certification of these components gives confidence in their interoperability and capability of becoming a part of an existing ecosystem," notes Lecheler.

Benefiting the Lighting Value Chain
Having components available that comply with and are certified in accordance to such standards benefits luminaire OEMs, component manufacturers, specifiers, and end-users alike. For example, an OEM's design of a new luminaire is facilitated by the availability of many components of different types, all of which are based on standardized interfaces. Having certified components of different types readily available alleviates the need to check whether they will function together.

"Zhaga, the global lighting industry organization, puts the spotlight on interoperability."

DEE DENTENEER, SECRETARY GENERAL OF THE ZHAGA CONSORTIUM

By defining what is required for components to work together, interface specifications benefit component manufactures too. Products manufactured in accordance with such an interface specification require less, or even no, co-development. It also eliminates the hassle of having to deal with companies providing complementary components.

“No longer concerned about whether their products are interoperable, these companies can now focus on innovation and differentiating features,” explains Denteneer. “These products then become part of a richer ecosystem of complementary products, which ultimately benefits the end customer.”

Having interoperable components based on standardized interfaces also means LED luminaires can be upgraded and serviced – particularly if the interface supports plug-and-play interoperability. “This advantage is especially appealing to end-users and specifiers,” adds Denteneer.

The ability to upgrade and service an LED luminaire plays an important role in the various stages of a luminaire’s life cycle. For example, replacing a component in-the-field not only fixes the broken part, it could also serve as an opportunity to adjust, upgrade, or even extend a luminaire. More so, it allows end-users to separate certain decisions (e.g., they can first decide on the luminaires and later about adding sensors for smart applications), thus easing both project planning and execution.

Finally, during the end-of-life treatment of a luminaire, plug-and-play interoperability allows components to be ‘unplugged’ – a feature that supports the circular economy and facilitates sustainable recycling.

Addressing Challenges Head On
Despite these advancements in interface specifications, challenges remain. For example, interoperable luminaire components require a technical alignment of all interface aspects, including electromagnetic compatibility. There’s also the issue of how the module driver interface makes it difficult to match a module to a driver (e.g., when exchanging modules in the field). The specification of the thermal interface between LED modules and luminaires is another challenge that needs to be addressed.

“We must also provide specifications that ensure the minimum level of functionality necessary for interoperability whilst leaving room for performance differentiation,” explains Lecheler. “This means ensuring that different suppliers provide products with different performance characteristics on top of the specified, minimum functionality.”

Finally, there’s the challenge of legacy management. “Legacy management must be considered so that a new generation of components is still interoperable with all the other components in the luminaire,” adds Lecheler.

Zhaga is addressing all these challenges head on. For example, it is developing standards that evolve with market and/or technology changes and is working to demonstrate the technical feasibility of using reference luminaires for the EMC testing of LED modules and drivers. The consortium is also taking concrete steps to future proof LED luminaires.

“Zhaga is developing the standardized interfaces needed to support the interoperable components that make lighting both connected and serviceable,” concludes Denteneer. “This work will ultimately benefit companies and end users along the entire lighting value chain.” ■

Enabling Optical Fingerprint Sensors with IR Wavelength at 1380 nm

Instrument Systems has developed a modular high-end IR test solution that meets the requirements of optical under-display fingerprint sensors with wavelengths above 1100 nm. As the IR radiation at 1380 nm is verified to avoid burn-in phenomena, the requested test equipment needs to be a high-end solution: high-resolution and calibrated for precise measurement of radiometric quantities, pulse measurement in the µs range and with temperature control.

IR emitters at 1380 nm enable under-display fingerprint applications without burn-in phenomena but require high-resolution test equipment for precise spectral and power characterization.

IR radiation is ideally suitable for sensors and the transmission of data. Typical applications are 3D sensing in consumer electronics (e.g. time-of-flight), automotive engineering (e.g. LiDAR) and fingerprint sensors. Especially for smartphones, under-display fingerprint scanning is the most widely used technology to unlock a device comfortably and safely. The light output used for this application was previously positioned at a wavelength of around 940 nm. Unfortunately, at this specific wavelength burn-in phenomena occur in OLED displays. A solution for this disadvantage is to use infrared (IR) radiation at 1380 nm. As the application stays the same for the user, the shift from lower to higher wavelengths in the NIR requires other high-resolution and calibrated test equipment for the precise measurement of radiometric quantities, pulse measurement in the µs range and temperature control.

Instrument Systems has developed a modular high-end IR test solution to meet the requirements of optical under-display fingerprint sensors with wavelengths above 1100 nm. The core of this system is a high-end spectroradiometer of the CAS 140CT IR series, optimized for wavelength measurement in the near-infrared range (model IR1). With the cooled InGaAs line sensor, model IR1 covers a wavelength range from 780 nm to 1650 nm and features thermoelectric cooling of the sensors down to a temperature of -10°C. This ensures low noise and excellent long-term stability. The high-gain option enables the sensitivity range to be significantly extended to include low power applications. A high-resolution model with a wavelength range from 1300 to 1440 nm additionally enables detailed investigation of narrow-band radiation sources with an optical resolution <1 nm. Combined with integrating spheres with highly reflective PTFE coating, a calibrated and fast photodiode, and LED-based calibration standards, Instrument Systems offers highly flexible system solutions with a calibration traceable to national standards such as PTB or NIST. ■

LpS Digital: Lighting Conference & Exhibition 2021

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

Experience the Future of Light

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

Unique Global Reach in the Lighting Sector

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

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

Lighting Industry & Technology Channel

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

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

Lighting Design Channel

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

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

Benefits for Conference Authors

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Benefits for Virtual Exhibitors

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The Tiger Leaves Its Skin Behind – Chung-Hoon LEE, Founder and CEO of Seoul Semiconductor

Chung-Hoon LEE
Mr. LEE is the founder and CEO of Seoul Semiconductor, a farmer's son, majored in Physics, received his MBA, and established Seoul Semiconductor, a global leading LED manufacturer, when he was 40.

In our interview series, we had the opportunity to talk to Mr. LEE, the founder and CEO of Seoul Semiconductor. The power of motivation turning into the presence of an innovative global company in the lighting sector is impressive.

LED professional: It is a great honor for us to do this interview with you, Mr. LEE. Thank you very much for your time.

Chung-Hoon LEE: Thank you, too.

LED professional: Can I ask you briefly about your career and what mission you have defined for SSC?

Chung-Hoon LEE: First, I am grateful for your interest in Seoul Semiconductor [1]. I majored in physics in college. While serving as a first lieutenant in the military, I read a newspaper article about Jimmy Carter (the 39th American president, 1977-1981) – the son of a farmer – being elected president of the United States. I was born as a farmer's son like President Jimmy Carter. Seeing how Jimmy Carter became the president of United States, I took a moment to look back at myself drinking and fraternizing with friends every day. That moment became a turning point of my life, and I established the goal of building a company in the future. To that end, I became an employee of a mid-sized company and served the company for five years to learn management. Also, to gain a more profound knowledge about management, I left for the United States in my 30s and completed my MBA while working part-time. I chose to continue serving the company for seven more years to secure more funds to establish the corporation. The year I turned 40, I was finally able to establish Seoul Semiconductor by adding more funds with my house as collateral. An old Korean proverb says, "a tiger leaves its skin behind after death, and a person leaves his/her name behind after death."

LED professional: Before we get into the individual topics, I would like to ask you to please give us an overview of the corporate structure of Seoul Semiconductor. How is your enterprise structured, and which core markets does it serve?

Chung-Hoon LEE: Seoul Semiconductor is a global compound semiconductor provider focused on LED and laser diode (VCSEL) products for 4 applications including indoor and outdoor lighting, automotive, IT products for display, and Violeds using ultraviolet rays. We also operate 4 production plants in Korea, China, Vietnam and the U.S., and 6 R&D centers. We have an extensive product portfolio with all wavelengths ranging from 200nm to 1400nm including ultraviolet rays (UV), visible rays for blue, green and red, and infrared rays for IR LED and LD/VCSEL, in addition to optoelectronic products. With a differentiated product portfolio, Seoul Semiconductor provides a wide range of industries with optimal light sources and solutions.

LED professional: If we look at the value chain, there are very different approaches from LED manufacturers. What is SSC's strategy in terms of components, modules, or even finished products?

Chung-Hoon LEE: I think that faith and commitment are very important for customers under the management principle of "No Competition with Our Customers". As I mentioned earlier, Seoul Semiconductor has focused on full line manufacturing such as epitaxy, fabrication, package and modules for 4 applications which not include any finished products.

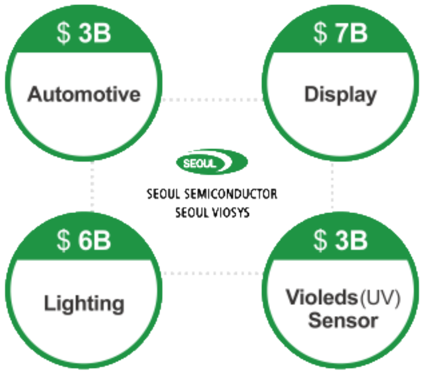


Figure 1: Compound Semiconductor Market with a CAGR of over 10%. Seoul Semiconductor's four leading applications on the compound semiconductor market. Sources: SU2020, Yole2020, SSC estimate.

LED professional: How do you see the core markets developing - where are the growth areas, and are there stagnating markets?

Chung-Hoon LEE: *"You can live without a house, but you cannot live without light."* Light was born along with the Earth 4.6 billion years ago, and the first plants 450 million years ago, the first insects 340 million years ago, and humans, for 7 million years, have also evolved along with natural sunlight. Since then, humans have also evolved in accordance with the sunlight spectrum, which is the light intensity by wavelength. Accordingly, it means that plants, fish, animals, and the people on Earth need natural light to experience a clean, healthy, and secure life. For instance, the human body has an internal 24.2 hour body clock. The solar cycle is 24 hours, and humans maintain their health according to this solar cycle by resetting the time with light every morning. As artificial lighting began to be used, the spectrum of the light became different from sunlight, and the time period for resetting our body changed. Therefore, the circadian rhythm is disrupted, the myopia rate has increased, and the number of insomnia patients has increased.

In addition, unlike sunlight, generally used LEDs and conventional artificial lighting make it difficult for fish, animals and plants living in aquariums and zoos to naturally produce vitamin D and they may suffer from various diseases. Bacteria provide beneficial effects to humans and the planet, but bad bacteria are the cause of disease. UV technology is essential to eliminate bad bacteria and lead a balanced life. Violeds technology can quickly and effectively kill 99.437% of SARS-CoV-2 in less than one second. Testing was conducted in December 2020 through KR Biotech, a South Korean-based research institute specializing in sterilization testing of the new coronavirus. In cooperation with SETi (Sensor Electronic Technology) for the past 15 years, Seoul Viosys, an affiliate of Seoul Semiconductor, developed Violeds which has been covered under ITAR (International Traffic in Arms Regulations).

Accordingly, Seoul Semiconductor has innovative technologies, which will lead core market, such as sun spectrum LED 'SunLike' [2] for human circadian rhythm to match to human DNA, UV LED 'Violeds' for water, air and surface disinfection, package-less LED 'WICOP' [3] for automotive and display applications, and 'VCSEL' technology for autonomous driving and connected transportation.

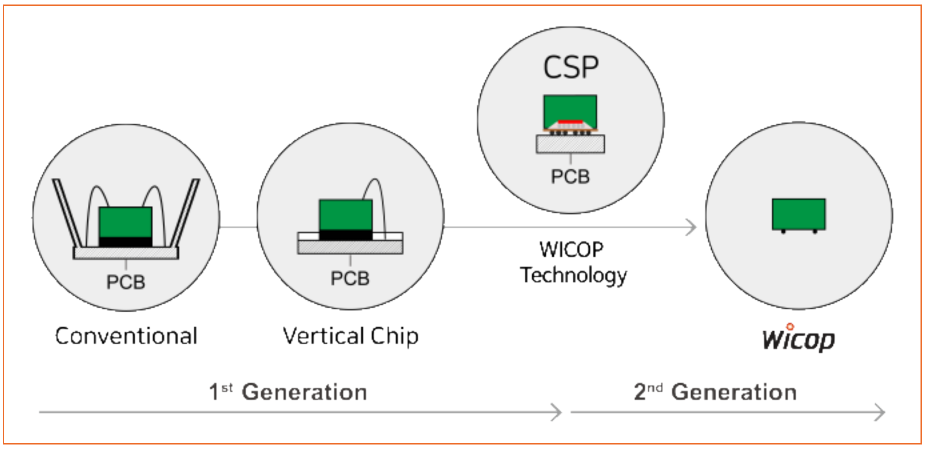


Figure 2: LED size reduction with WICOP's technology based on the bare chip mounting process.

Figure 3: SunLike natural sun spectrums for Morning – Noon – Evening Colors.

"A tiger leaves its skin behind after death, and a person leaves his/her name behind after death."

OLD KOREAN PROVERB

LED professional: From your perspective, how has the LED business changed and what are your expectations for the industry, the design, and the application or user?

Chung-Hoon LEE: As the mass-production of RGB (red, green, blue) LEDs with the three primary colors was achieved three decades ago, all relevant companies in the market started focusing on producing brighter LEDs. Afterwards, companies started focusing on USD/lm and lm/W related to price and saving electricity cost to expand distribution. From the late 2010s, companies started focusing on color quality rather than price competitiveness. In addition, the necessity for a light source similar to natural light contributing to the healthy lives of flora and fauna is gaining attention. They say that nature teaches humans many great things. I am confident that the technology to create light the most similar to natural light is more important than anything. Seoul Semiconductor has been carrying out different studies on people, plants, and animals in cooperation with research teams from the most outstanding hospitals and universities based in the United States, Europe, and Asia. This enabled us to achieve innovative results which will be introduced in the third quarter. Wouldn't it be astounding to learn that light helps studying performance of students, or to learn that light has beneficial effects for memory enhancement?

LED professional: SSC has repeatedly come up with exciting innovations, whether in driverless systems or optimized light spectra. Spectra-optimized LED system solutions are now in high demand in the general lighting, horticulture, and automotive sectors. How do you see these developments, and what solutions does SSC offer?

Chung-Hoon LEE

Chung-Hoon LEE: I am pleased to learn that you are aware of our driverless system. Seoul Semiconductor developed Acrich powered by AC in addition to high voltages of 12V and 24V to provide more eco-friendly and more efficient LEDs to our customers. The AC high voltage LED is a technology that contributes to reducing the cost or volume of the driver by over 30%. Therefore, high voltage LEDs and high voltage drivers and SunLike (a natural sun spectrum LED) are significant in the field of lighting.

Demand for WICOP technology to provide thinner and lighter solutions is increasing in the field of display. As per the advertorial article published by the Wall Street Journal, 20% of global TV display uses WICOP for thinner and lighter TV sets. Also, the RGB chips in micro LED started being mass-produced in the form of micro pixel LEDs in which RGB was applied to a single chip rather than manufacturing and transferring each Red, Green, and Blue chips. This product is being supplied to the display market which totals 100 trillion dollars and encompasses the LCD and OLED markets. As mentioned in the advertorial article published by The Financial Times, approximately 10% of all vehicles produced by the automotive industry uses WICOP technology. It is predicted that micro pixel used for interior/exterior display and communication will take up a considerable portion of the market in the future.

In addition, Seoul Semiconductor was able to develop filament bulb technology of classic design in cooperation with the UCSB research team where Nobel Prize winner Professor Shuji Nakamura has been a member of for about 20 years.

LED professional: **SSC has a long cooperation history with Toshiba Material in regards to full-spectrum phosphors. How is this cooperation developing?**

Chung-Hoon LEE: Seoul Semiconductor participated in joint-development of SunLike, an LED technology providing light the most similar to the sun spectrum in cooperation with former CEO Kobayashi of Toshiba Materials. However, differing cultures and points of interests of Toshiba Materials and Seoul Semiconductor posed difficulties in expanding promotion. Nevertheless, we have succeeded in reaching an agreement with Toshiba and plan to announce a new strategic business model within two months. This will enable an environment in which business could be led by a single company. We ask for your keen attention. Our strategic plan will be officially announced in the 3rd quarter.

"You can live without a house, but you cannot live without light."

CHUNG-HOON LEE

LED professional: **Is there any exciting new product or product launch you want to share with our readers in the field of spectral tuned LEDs?**

Chung-Hoon LEE: There are new products for lighting, display, automotive, and UV, but it is difficult to release them all because this is an issue that requires discussion with the leaders of the four divisions. However, what I can say for sure is, Seoul Semiconductor is leading the development of innovative technology by investing over USD 100 million every year in R&D over the past 10 years and it holds 15,000 patents and more a than thousand application patents, which can create new valued technology. But if I mention our future products and technology in addition, WICOP revolutionary technology is widely used for the display, lighting, and automotive with high-power LEDs. We also provide automotive LED solutions optimized for adaptive driving beams (ADB) based on micro pixels. SunLike natural sun spectrum LED for human centric lighting and Violeds to disinfect air and surfaces within 10 minutes will also lead the LED market and industry.

LED professional: **Sustainability, Ecodesign, and Circular Economy are highly crucial for our world in general. May I ask you about your thoughts and positions in these areas?**

Chung-Hoon LEE: Sustainability and eco-friendliness are the fundamental rules for the company. Two of my creeds as a son of a farmer are: "It is a sin for

Wicop	Light, thin, short and small / Core technology of Mini and Micro LED
SunLike	Light source for healthy circadian rhythm to match 24-hour body cycles
violeds	Disinfect virus and bacteria
Filament	Filament LED with similar design to conventional incandescent bulbs
AcrichMJT	Easily connectable to 220V for home use with less number of LED
Acrich Driver	Connectable to 220V for home use and 20% cost reduction
UCD Phosphor	White LED light source with color rendering close to sunlight
Over 10K hour	Use 5 years available for 5 hours a day (Up to 10 times longer lifespan than incandescent bulbs)
Over 150 lm/W	Electricity cost less than one-tenth compared to conventional incandescent bulbs and one-third of fluorescent lamps

Figure 4: The world's first and second generation LED technologies of Seoul Semiconductor.

a company to go bankrupt" and "We should always embrace the natural environment". In 1994 – almost 3 years after starting the company in 1992 – I chose the color green as the corporate identity and soon our corporate logo was designed and put to use.

The LED product is eco-friendly as it is because it is designed to last longer and not use harmful chemicals such as mercury, and our Violeds technology particularly provides clean air, clean water, and clean surfaces by disinfecting harmful viruses such as SARS-CoV-2. Seoul Semiconductor is always with nature, which provides inspiration for sustainable products and technology.

LED professional: I would like to ask a question regarding the adaptation of LED applications. In your view, are there factors that can accelerate the changeover to LED solutions? Can the industry contribute here, or would it be necessary to provide more stimulus in the planning area?

Chung-Hoon LEE: As I mentioned earlier, I would like to tell another story. Some people say that Seoul Semiconductor is filing a lot of patent litigation and seems to be greedy. However, Intellectual Property provides hope for young entrepreneurs and small businesses. But it is very disappointing that even global, established companies knowingly use products that infringe on others' patents.

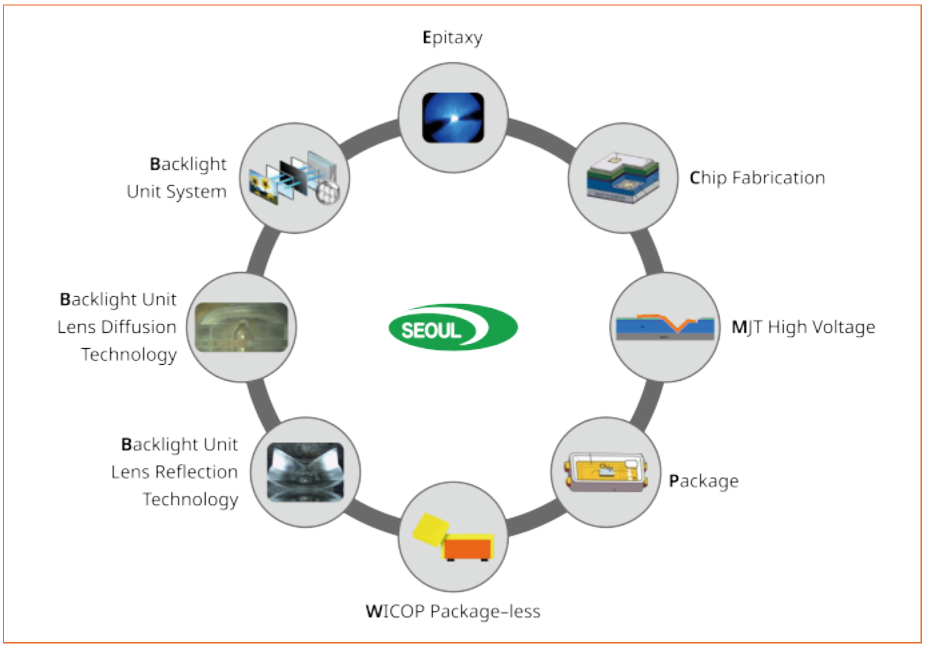


Figure 5: Seoul Semiconductor's technology overview.

Figure 6: Seoul Semiconductor Headquarters.

And Intellectual Property is an incredible tool that allows people to break through class barriers, enabling small businesses and young entrepreneurs to compete with anyone. Since our industrial revolution, the infant mortality rate has declined from 43% to 3%, while access to electricity has increased to reach 85% of the total world population, and the illiteracy rate has also been reduced significantly. So Intellectual Property enables to make life to be more transparent and safer. When the LED market that respects patents is formed, I believe it will bring continuous disruptive innovation and LED solutions.

LED professional: What is your and SSC's recipe for success? What drives you and helps bring excellent solutions to the market?

Chung-Hoon LEE: I think and feel that it is meaningful for a person to leave behind a masterpiece, a small yet valuable footstep that benefits the world. If I am able to write new history with light, if a son of a farmer is able to stand on the top of the world, I am certain that the success story of Seoul Semiconductors will instill hope to numerous sons of farmers, to a myriad of businessmen from small and medium sized companies, and aspiring youth struggling in competition with giant conglomerates yet still with the hope of entrepreneurship in their hearts.

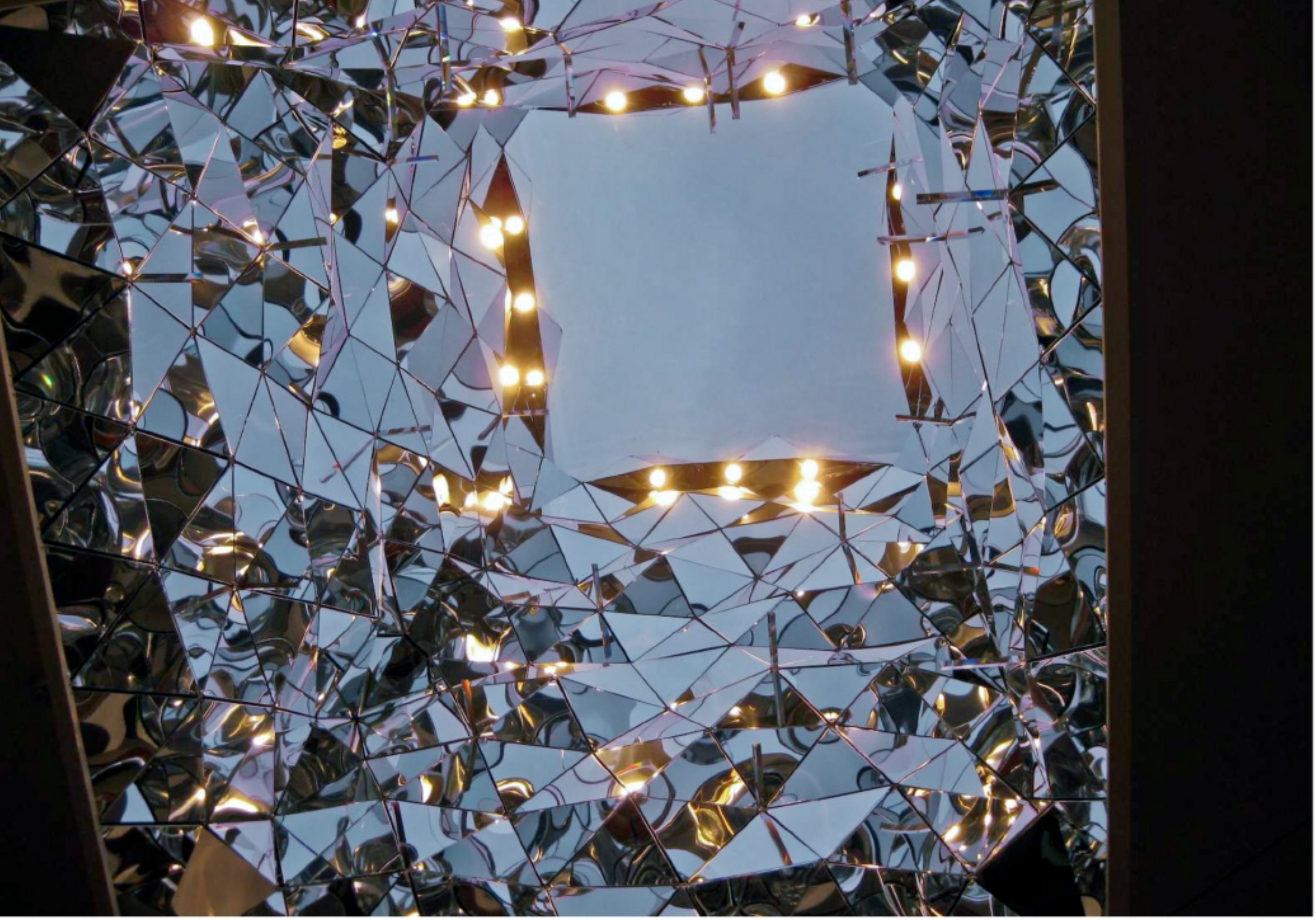
To build such a history, I am sparing no effort to create the most transparent and the most equitable company in the world. I hope that many who are working with me, if not all, will say "Chung-Hoon LEE was a good man. Seoul Semiconductor was a good company". To that end, I will strive for people to acknowledge our company as a company of good people rather than prioritizing profit.

LED professional: It was a great pleasure talking to you! Thank you again for your time, and we are looking forward to seeing future innovations.

Chung-Hoon LEE: Thank you. ■

References

[1] http://www.seoulsemicon.com/en
[2] http://www.seoulsemicon.com/en/technology
[3] http://www.seoulviosys.com/en/technology/wicop/



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DALI-2 Touchpanel

A multifunctional control unit with up to 16 freely configurable buttons and sliders. The device can be adapted to a wide variety of applications. Several standard user interfaces are available and customer-specific designs can be implemented upon request.

image: Tunable White, RGBW, Brightness and Scenes

In addition to the standard functions of dimming, switching, scene recall, etc., predefined macros such as setting the colour temperature, dynamic scenes, and sequences, as well as user defined command lists are supported. The number of buttons and the associated DALI commands can be set in the DALI Cockpit Software.
The device can be mounted on commercially available flush-type installation boxes and is supplied by the DALI line.

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The Latest DALI Enhancements Mark the Start of a New Controls Era – Paul DROSIHN, General Manager, DALI Alliance

Paul DROSIHN, FInstLM
Mr. DROSIHN has been General Manager of the DALI Alliance since May 2019. He is a Member of IEEE and AMBA, and a Fellow of the Institute of Leadership and Management.

DALI Alliance's General Manager Paul Drosihn, together with the DALI Alliance team and its member companies, heralds a new era for lighting controls. DALI IP-based and wireless lighting communication (DALI+) opens up new networking and application possibilities for the lighting sector in buildings and cities. LED professional was pleased to discuss a few deciding issues with Mr. Drosihn.

LED professional: **Hello Paul! We are pleased that you have agreed to answer a few more in-depth questions after the publication of the technical report about DALI+ and the DALI Gateways [1]. Thank you for taking the time.**

Paul DROSIHN: I'm delighted to be here!

LED professional: **The DALI organization has changed its name from DiiA to DALI Alliance[1]. Was it just the name, or did the structure/organization also change?**

Paul DROSIHN: It was just a branding change, no changes to our legal structure. We just felt that compared to DiiA and Digital Illumination Interface Alliance, DALI is recognizable globally as the leading lighting controls standard, so it makes sense to have that word in our organization brand name.

LED professional: **When it comes to lighting controls, what position does DALI have? Worldwide market penetration/acceptance?**

Paul DROSIHN: DALI has been established over three decades, with a huge variety of installations across the globe. Pal Karlsen describes it as "the largest wired digital open protocol in the world for lighting" [2]. According to a report from "Research and Markets" [3], DALI is the largest segment for smart lighting, with 15% CAGR expected over the next five years. We see continued support from members and membership continues to grow.

LED professional: **What other lighting controls system are relevant? How do you see the activities of "Home Control Systems" with smart devices such as from Amazon, Apple, and Google?**

Paul DROSIHN: Of course, there are others working with lighting controls, but DALI is by far the most feature-rich, and is dedicated to lighting. We have focused on standardization, and interoperability based on certification, the core strengths of our organization, driven by our members. So over the last three decades DALI has evolved to include the most features, the largest installed base and verified interoperability (based on testing, including plugtests). We have built liaisons with other parties, to enable the benefits of DALI to be accessible through other networks, and interact with other systems.

LED professional: **When it comes to DALI specifically, there are three important terms: DALI-2, D4i, and DALI+. Could you please explain the exact differences between these terms?**

Paul DROSIHN: DALI-2 is the certification program that goes further than the original DALI and significantly improves the interoperability, especially cross-vendor, thanks to rigorous testing and independent certification.

D4i[2] is aimed more at individual luminaires, it is based on DALI-2, but also requires some minimum features such as the Luminaire, Energy and Diagnostics data (which are optional in DALI-2), as well as power supply requirements for connecting control devices such as sensors or communication nodes.
Think of it like a "DALI-inside" the luminaire. When also certified by Zhaga, which defines requirements for mechanical/connector aspects of the luminaire, you have "Plug and play" standardization, where Zhaga is the "plug" and DALI/D4i is the "play".

DALI+ is new, and enables wireless or IP-based communication. It is still DALI but with the ability to use Internet Protocol (IP)-based or wireless carriers instead of the usual dedicated pair of wires (known as the DALI bus) that carries the DALI commands. With a DALI+ bridge you can connect an existing wired DALI installation to a DALI+ wireless or IP-based system.

LED professional: **So, with DALI+ you've opened the wireless and IP world to DALI lighting controls. Do you think wireless will be more important in the future? Do you expect hybrid solutions?**

Paul DROSIHN: Yes absolutely. The market will decide this. Really, what we are doing is giving options, whilst keep-

[1] The DALI Alliance has almost 300 members (about 10% are Regular members) and can be reached on https://www.dali-alliance.org.

[2] D4i was a new trademark, focused on IoT-ready intelligent luminaires, sometimes also referred to as LLLC (luminaire-level lighting control).
D4i is based upon DALI-2 (all D4i products are also DALI-2 certified). Some in the industry have assumed it means DALI for IoT, which is a useful coincidence. (P.D.)

ing the standardized behavior and interoperability backed by certification[3 4]. We already see "wireless" being important; our members requested this as a priority. I'm sure there will always be wired controls, and wired gives many advantages, particularly as for the foreseeable future you will always need power to a luminaire. However, we do see wireless as particularly strong for retro-fit, for historical buildings for example. Wireless is also very useful to add flexibility to spaces, particularly for sensors or controls, as spaces need to become more dynamic, with offices changing to hot-desking, or using more conferences rooms or other types of use. So in reality we do expect hybrid to become the norm, and the market will decide the mix, differing by application or individual project requirements.

LED professional: What are the main advantages of pure systems such as wired-only or wireless-only?

Paul DROSIHN: This depends deeply on the application. Wired systems offer predictable network behavior, and avoid any potential connectivity issues that may arise in a built environment. Also, DALI wiring can be installed along with the power cables. One advantage of wireless is flexibility; it can be much easier to add sensors and new luminaires to an existing lighting network, or to relocate devices when a building is refurbished or repurposed. Not needing to lay data cables through walls, ceilings or floors can be a considerable advantage in time and expense. (But of course luminaires and other lighting devices still require power.)

An additional advantage of wireless specific to DALI+ is increased addressing, indeed with IP-based that's almost unlimited.

LED professional: Which wireless network does DALI+ support?

Paul DROSIHN: Currently we are working with Thread[5], a low-power wireless mesh networking protocol based on the universally supported IP and built using open and proven standards. DALI+ with Thread will be the first certification program, and further DALI+ certification programs utilizing carriers other than Thread are expected to follow soon. In addition to Thread, our new DALI+ specification already supports Ethernet, Wi-Fi and other IP-based protocols.

LED professional: Are there any new data/functions/commands in DALI+?

Paul DROSIHN: DALI+ uses the same DALI commands throughout, so you get the same lighting control features and data, the main difference is the carrier. However, a key potential advantage of DALI+ is the addressing, which goes beyond the 64+64 per DALI wired subnet. For IP-based DALI+ with Thread, this will be almost limitless, making it easier to install and manage large networks.

LED professional: The first version of this specification supports IP-based protocols such as Thread, Ethernet, and Wi-Fi. But the main focus is given to Thread. Why is that?

Paul DROSIHN: All our work on specifications and certification is guided by the priorities set by our members, as well as the availability of volunteers to carry out the necessary tasks; these include creating the specifications and test procedures, and evaluating the tests so that certification can begin. For DALI+, our members decided that the highest priority was to work with the Thread Group to develop a robust DALI+ with Thread certification program. Once this work is complete, it should provide the basis to develop further certification programs with other carriers. And, future versions of the DALI+ specification may support other carriers as well.

LED professional: Besides DALI+, there are also two DALI Gateways available for Bluetooth mesh and Zigbee. What's the difference between DALI+ and DALI Gateways?

Paul DROSIHN: Gateways translate or map the behavior from the other network to DALI, so a DALI device can be added to a Bluetooth or Zigbee network, using a gateway. But with gateways the control is from the network side. DALI+ talks DALI everywhere, without translation or mapping, everything is DALI, regardless of the carrier, so the only thing to take care of is to make sure a compatible carrier is used throughout.

LED professional: Security is always key. The risk of hacking DALI+ systems and getting into companies' networks is fundamental, and of course, you've considered that. How secure are the DALI+ systems and what about the gateway security?

Paul DROSIHN: Gateways rely upon security features of the wireless network on the wireless side, and wired DALI on the DALI side. DALI+ uses security layers provided by the underlying protocol, with additional application-layer security features for DALI+ with Thread. We have working liaisons with the relevant partners, Bluetooth SiG, Zigbee Alliance (now Connectivity Standards Alliance) and Thread Group and our technical teams work with those partners.

> "*DALI+ uses the security features of the wireless networks, and there are some additional application-layer security features for DALI+ with Thread. The people who specify buildings, not only for lighting but for IP-based systems, already have the implementation knowledge; perhaps just not focused on lighting. In the future, there will be more commonalities in the specification. That's also why we joined the IP-BLiS group - to try to get all elements in a building to interact in a robust and secure way.*"
>
> PAUL DROSIHN

[3] DALI Test Equipment is available from LICHTVISION Engineering http://www.lichtvision-engineering.com.

[4] Accredited DALI Test Houses can be found on https://www.dali-alliance.org/testing/test-houses.html.

[5] Thread operates as a separate mesh communication network within buildings. It's based on IEEE 802.15.4 MAC/PHY. The Thread Stack provides security and commissioning features with UDP (User Datagram Protocol), IP Routing, and 6LoWPAN (Acronym of IPv6 over Low-Power Wireless Personal Area Networks). The top application layer is used for DALI+. The Thread Group can be reached on https://www.threadgroup.org

LED professional: Where exactly will manufacturers find the specifications of DALI+ and the DALI Gateways? Which standards will be updated for DALI+ and the Gateways? Can you give us a quick roll-out of what will come?

Paul DROSIHN: The specifications for the wireless to DALI gateways are Part 341 Bluetooth mesh to DALI, and Part 342 Zigbee to DALI. These will be transferred to IEC 62386 in due course. The DALI+ specification is an update to the already published Part 104, with changes and additions. These are already published on our website and available to our members. They are also available to non-members on our website with a simple email sign-up. As mentioned, work is in progress on the tests for certification.

LED professional: With DALI+, D4i, and DALI-2 there is a powerful lighting control system available. Do you see the development of DALI finished, or are there any plans for further extensions and upgrades?

Paul DROSIHN: Firstly, we must deliver on the certification programs for specifications, including gateways and DALI+ as well as features such as DALI emergency and color control. As certified products become more widely available, lighting designers, architects, facility maintenance teams and downstream DALI users will all benefit from further project innovation. Looking further ahead, we see opportunities for industry harmonization and convergence in currently isolated building systems such as HVAC, lighting, security and IT. That's why we recently joined IP-BLiS[6], the 'IP Building & Lighting Standards' market interest group, which promotes alignment around IP-based networks for enhanced building control and management. With extensive data from DALI sensors and controllers, there are clear opportunities to better connect with other building systems. Of course, all this will be while maintaining our continued core focus on interoperability and future-proofing through globally recognized standardization and certification.

LED professional: With integrated lighting, meaning for visible and non-visible effects and its usage, we enter a new area. Would this also include controls? Are you thinking in this direction as well?

Paul DROSIHN: I think technology will enable new, unexpected or previously unthought of, concepts: that's what technology does. A favorite quote of mine is from Henry Ford, who said, "If I had asked people what they wanted, they would have said faster horses". Once technology is enabled, the market will decide what it wants and the DALI-Alliance will ensure we keep in tune with that, while continuing to focus on the "standardized and interoperable" that is our core value. I think that with gateways enabling luminaire-level controls and sensing, and with DALI+ enabling alternative carriers, these possibilities expand very quickly.

LED professional: What are your strategic goals for the further development of DALI and the DALI Alliance?

Paul DROSIHN: To get closer to our market. What I mean is to listen more to those that interact with DALI, at all levels, and try to be more responsive to their needs. However, we are a standards organization, and rely heavily on the support of our members, especially our Regular members. Therefore, a key challenge is to ensure that we not only grow membership, but also grow the contribution of our members to the Alliance.

Finally, I see a connected, data-rich world, but it's a bit fragmented or siloed at present. I can see even more opportunities to reduce energy consumption and improve environmental conditions. "LED-ification" enabled massive energy savings, and more control, especially dimming. In turn this enabled further energy usage reductions. Sensing went further still and intelligence is adding a new dimension. Lighting control and sensing will become even more connected and harmonized across segments, enabling us to go even further still. The DALI Alliance must do everything it possibly can to make that journey as fast and as smooth as possible.

LED professional: Paul, that was an excellent outlook. Thank you so much for taking the time to talk to us. I hope we can meet in person again soon.

Paul DROSIHN: Thank you very much for the opportunity. ■

6 https://www.ipblis.org

About Paul DROSIHN

Paul is General Manager of the DALI Alliance (also known as the Digital Illumination Interface Alliance or DiiA), an open, global consortium of lighting companies that drives the growth of lighting-control solutions based on internationally-standardized Digital Addressable Lighting Interface (DALI) technology. Paul is a highly qualified and experienced management professional with more than 30 years' experience in the electronics and LED lighting industries. He has held a number of senior roles in management, sales, operations, business development and strategic marketing, at companies involved in electronics, manufacturing and management consulting. He is a Member of IEEE and AMBA, and a Fellow of the Institute of Leadership and Management.

References

[1] LpR85 May/June 2021, https://www.led-professional.com/downloads/LpR85_Full_013219.pdf

[2] LpR79 May/June 2020, https://www.led-professional.com/downloads/LpR79_Full_843992.pdf

[3] Market Research https://www.businesswire.com/news/home/20200226005519/en/Global-Smart-Lighting-Market-2019-to-2026

Repro-light: Sustainable Illumination for People and the Environment

The aim of the 3-year EU Horizon 2020 flagship project Repro-light ("Re-usable and Re-configurable parts for sustainable LED-based lighting system") [1,7] was to initiate a change in the European lighting industry towards circular economy and "healthy" lighting (HCL). For this purpose, LED luminaires with a modular architecture were developed, with the following aims:

- **The environmental impact is taken into account "from the cradle to the grave".**
- **The luminaires are already configurable by the end user already in the ordering phase (including individual 3D-printing parts by additive manufacturing technology).**
- **The individual needs (visual and non-visual) of the end user are considered during operation.**

The requirements of users from the industrial, office and healthcare sectors were determined with the help of extensive surveys and targeted focus groups. Based on this, new modular luminaire systems were developed, including new optics, sensor technology and control and monitoring ("intelligence"). New production concepts were developed and partly implemented in pilot installations.

Extensive life cycle analyses (LCA) were used to investigate the environmental impact of various production and utilization concepts [2,28] and the luminaires were optimized accordingly.

The intended sustainability of the luminaires in terms of the effect of the lighting installations on people was scientifically investigated in field and laboratory studies.

Sustainability in the European Lighting Industry

In Europe, approximately 15 million tons of electronic waste are produced annually [3], with a strongly increasing tendency. Whereas in the past the lamps and electronic parts of luminaires were simply replaced at the end of their service life (standardized interfaces). This is generally no longer possible with modern LED luminaires, which are electronic scrap that ends up in landfills and are generally exported to third countries for final disposal.
In the "Repro-light" project [1,7], an attempt was made to use innovative technologies and materials with matching smart production processes to develop sustainable modular luminaires. The essential components of these luminaires are interchangeable and can be configured for the respective application (e.g. different LED modules and optics), and their software can be updated accordingly. In order to minimize the ecological footprint of LED luminaires from raw material extraction through production and use to disposal, a comprehensive life cycle assessment study was carried out in the project [2,28].

Figure 1: Life Cycle Management [4].

Circular economy means that we must minimize the extraction of raw materials, energy consumption, and incineration and landfilling (waste), by increasing maintenance, reuse and recycling. An essential aspect is also the use of so-called critical raw materials [5], for which there is a supply risk (e.g. some raw materials for the production of LEDs, which come from China).

Table 1 shows the criteria for the Life Cycle Assessment (LCA) which was done by the project partner, IREC.

Abiotic resource depletion refers to the depletion of nonliving (abiotic) resources such as fossil fuels, minerals, clay, and peat. Abiotic depletion is measured in kilograms of Antimony (Sb) equivalents.

In summary, it can be said that for the raw material balance (abiotic depletion of resources), the metals used for electronics and LED boards and their recycling rates are decisive (rare earths, as well as gold, silver, copper, nickel, lead and aluminum and their by-metals). In the case of gold and silver and the rare earths, there is a threat of a shortage of resources, and in the case of the rare earths, there is also a dependence on China as a producer.

As far as the toxicity of the materials used is concerned, the mining of rare earths (toxic sludges) and the uncontrolled contamination with copper, iron, lead, nickel and silver are decisive.

For 98% of all other environmental impacts like CO_2 pollution (global warming), primary energy consumption, soil acidification and eutrophication the operation of the lights (energy consumption) is solely responsible.

Lighting is responsible for round about 5-10% of the primary energy consumption in industrialized countries (dependent on the local energy mix) [6], and with a similar dimension for the abiotic depletion of resources [7]. With the European Green Deal [8], the EU has launched a coordinated strategy for a climate-neutral, resource-efficient and competitive economy, and the lighting industry will also have to make its contribution [9,25].

Individual Mass-Production

Automation in industry is increasingly being replaced by "intelligent" robots, which will enable cost-effective individual mass production of products in the future (**Figure 2**).

One of the main aspects in Repro-Light was to design such a fully automated pilot production by the industrial partner Trilux to produce luminaires based on a modular architecture [9].

Another aspect of Repro-light was to implement a configurator which allows the client to choose individual combinations of components (e.g. optics) and product parameters (e.g. Luminous packages, luminous intensity distributions, etc.), and to make their own individual design by additive manufacturing methods [24]. A customized design of decorative parts can be done by special design modelling using a computational morphing algorithm.

Impact Category	Characterization factor	Unit	Description
Climate Change	Global Warming Potential **(GWP)**	kg CO_2-eq	The emission of greenhouse gases that lead to increased radiative forcing and raise in mean global temperature
Energy demand	Primary energy demand **(PE)**	MJ	The consumption of both renewable and non-renewable primary energy sources measured prior to processing
Abiotic Resource Depletion	Abiotic depletion potential elements **(ADPe)**	kg Sb-eq	The depletion of reserves due to the unsustainable extraction of non-renewable minerals
	Abiotic depletion potential fossil **(ADPf)**	MJ	Quantity of natural resources (crude oil, etc.) depletion
Acidification	Acidification Potential **(AP)**	kg SO_2-eq	The emission of substances that lead to the change in soil acidity and ecosystem damage
Eutrophication	Eutrophication Potential **EP**	kg PO_4-eq	The release of nutrients that lead to growth of algae and cyanobacteria and a relative loss in species diversity

Table 1: Life Cycle Impact Assessment [2,28].

Figure 2: Manual line production (left), individual mass production by robotics (right) [1,9].

Figure 4: Key facts of the Europe-wide end-user survey [12,27].

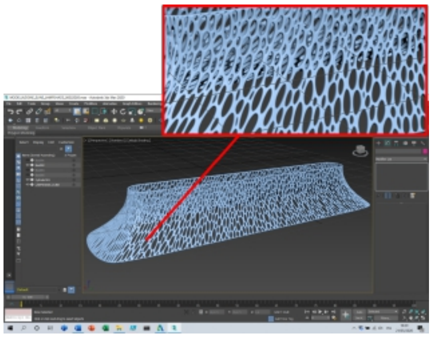

Figure 3: Configurator for 3D modelling by morphing algorithms [24].

Thus, a cost-effective production line was established with a luminaire configurator, connected to a SAP program and the assembly line with additive manufacturing by 3D-printing, which allows personalized adjustments and designs.

A User-centered Design Approach

Understanding User Needs

In order to assess the prevailing user requirements and wishes for future workplace lighting and to incorporate them into the further development of the project, a multidimensional survey of user needs was carried out in 2019. In addition to a comprehensive literature search and several focus groups with representatives from the professional world along the entire value chain, this also included a Europe-wide online survey of more than 1,100 end users [11,27].

The results showed a clear need for a generally improved workplace lighting and a widespread desire for a better user experience (**Figure 4**). Particularly in the context of the great variability of individual lighting preferences, the respondents stated that they would like to have more influence on their personal workplace lighting and that the lighting should also be different for different working tasks. Task-related default settings should therefore be made customizable and adaptable by the user. In addition, the majority of those surveyed would like more individual support for their way of working through automatic adjustments to current situations and requirements. In addition to their desire regarding an automatic adjustment of the color temperature based on the time of day in the context of human-centric lighting (HCL), this also includes future-oriented requirements like an automated recognition of activities and current individual needs. Accordingly, users see themselves as currently only insufficiently integrated into lighting solutions and, as part of the increasing digitalization of society, are placing increasing demands on lighting products regarding an improved interaction behavior and human-machine interfaces, which they already know and are used to through implementations in other technological areas. The relation to these modern concepts of information and communication technologies also explains the stronger expression of the results among younger respondents.

The Personal Table Light (PTL)

Based on the results of the assessment of user needs and the requirements for a sustainable lighting concept, the Personal Table Light (PTL, **Figure** 5) was developed; a personalized, intelligent lighting system, promoting the health, well-being, and integration of the individual user [7,13,26]. The basic idea of the PTL is to convert the workplace lighting from general lighting at the ceiling to individual lighting on the user's work desk. This not only enables more individuality, but the high illuminance levels required to achieve non-visual effects can also be achieved in an energetically efficient manner due to the close proximity to the user.

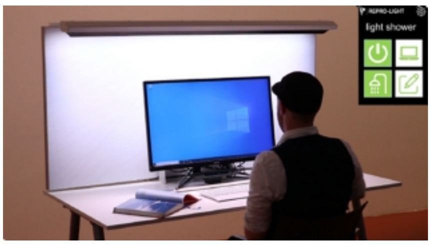

Figure 5: Personal Table Light (PTL)
© Bartenbach [13]

In terms of lighting, visual comfort and performance are perfectly supported by the PTL, as both vertical and horizontal work surfaces can be illuminated separately by means of a highly controllable, intelligent LED light engine. The illuminance levels,

Figure 6: The Personal Table Light (PTL) with adjustable light scenes (here: color temperature).

Figure 7: The PTL alternatively equipped with a vertical blue light.

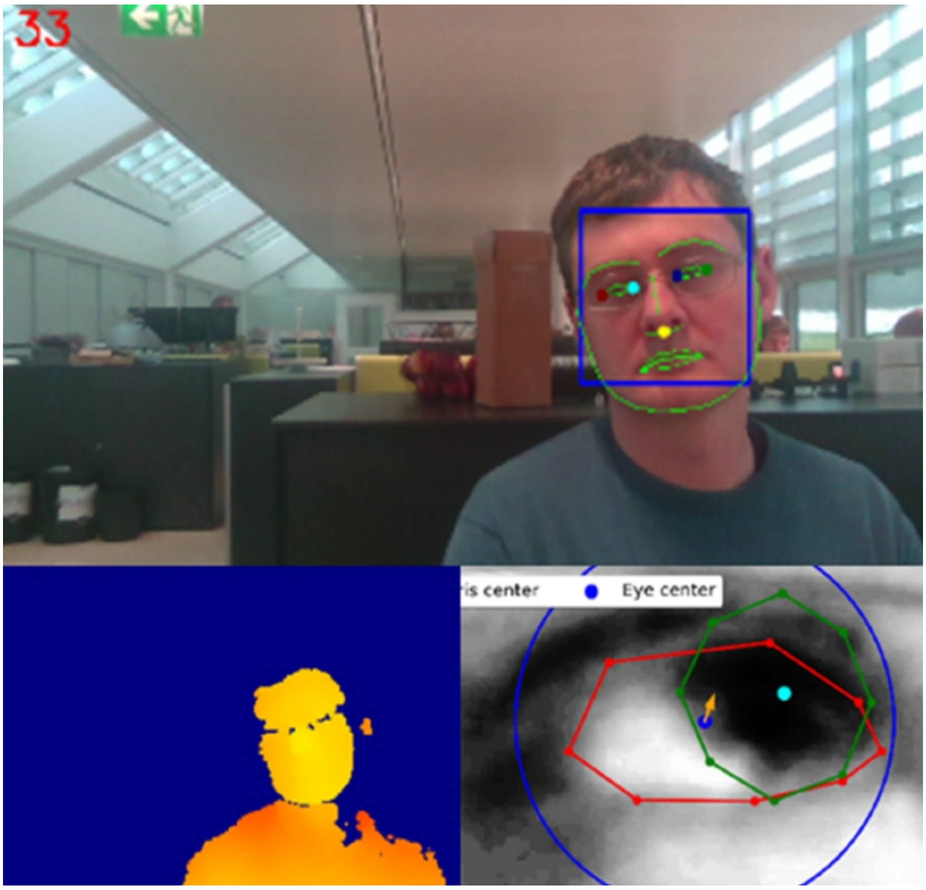

Figure 8: Output of the internal AI-based gaze detection algorithm [14].

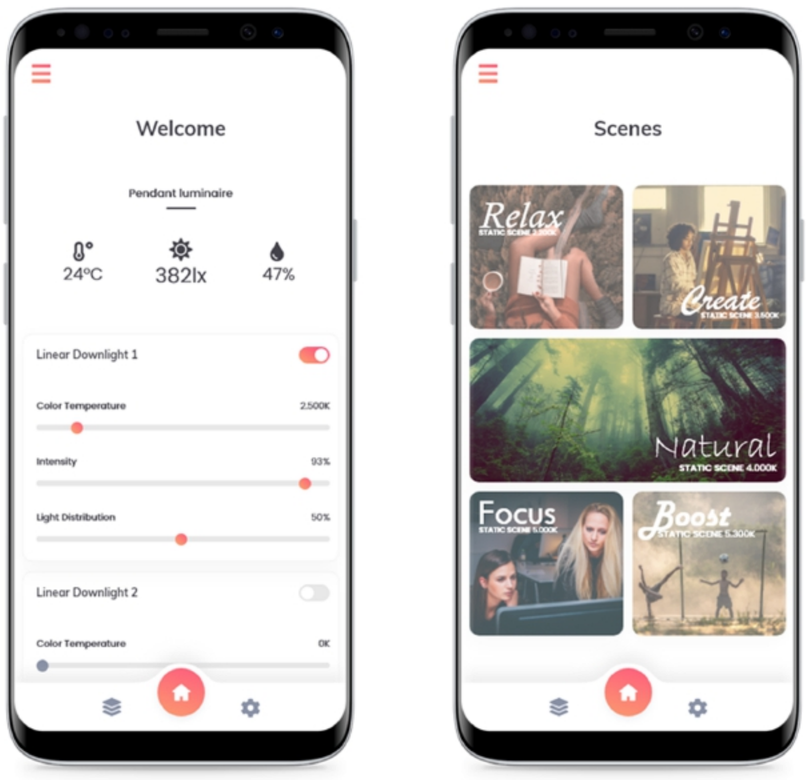

Figure 9: Design prototype of the web-based control software.

color temperatures (from 2200 K to 5700 K, or alternatively vertical blue light, **Figure 6**, **Figure 7**) and light distributions can be fully adjusted by the user via 24 separately controllable LED points. In addition, the PTL effectively delivers up to $E_v = 1500$ lx at eye level and 6000 lx at the desk, which makes it possible to supplement the lack of daylight and to achieve non-visual effects on mood, alertness, performance, and nightly sleep.

To meet the high user requirements, which resulted from the online survey, an embedded lighting control system was developed to be able to interact with the implemented, highly innovative sensor components. In addition to a continuous assessment of the environmental quality in terms of ambient temperature, humidity, air pressure and sound, a coded light-based depth camera is used, which not only allows to record the real presence of the user at the workplace, but also to recognize the current visual task by estimating the direction of view of the user in real time using machine learning algorithms [14]. This feature allows the PTL to adjust the light setting discretely and automatically based on individual preferences and current work task and thus to automatically offer an optimized lighting situation depending on the current activity (**Figure 8**).

The use of embedded control technologies and highly standardized IT protocols also makes it possible to implement innovative control concepts. For example, the control software is based on a microservice architecture, which uses independent, encapsulated subroutines to implement the required modularity of the optical components at the control level and significantly promotes both scalability and functionality in the long term. Additional functions can easily be provided by means of remote updates and can also be activated by the user and adapted to his preferences or needs. In addition, the integration of almost all sensors available on the market has proven to be possible without impairing the real-time capability of the lighting control itself. Among other things, this behavior is also made possible by the fact that conventional control protocols such as DALI were not used in favor of IT-based protocols. Especially in connection with the highly responsive AI control elements, a successful implementation with conventional control protocols would not have been possible considering the real-time requirements.

If desired, open interfaces enable the PTL to act as part of a higher-level system. However, the embedded control technology also makes it possible to operate the PTL independently using a plug-and-play mechanism. To interact with the luminaire, it is not even necessary to install an associated application, as the luminaire itself provides the user interface required for control via a browser based on innovative, web-based technologies (**Figure 9**). This not only increases the accessibility significantly, as the controls can be carried out synchronized via any smart end device. It also allows the functions of the highly modular control system to be made available to end users in the simplest way possible, as the application represents a direct mirror image of the existing, activated and individually set lighting functions. Furthermore, a simplified and anonymized user identification is made possible, based on which an extended individualization can be achieved. Finally, the implemented cloud connection allows an optional recording of user activities, which are analyzed in real time and used for ongoing optimization of the lighting system tailored to individual needs. This is especially interesting as the PTL applications are diverse, ranging from offices and student areas to medical and machine manufacturing workstations.

Usability and Accessibility Evaluation

In order to ensure that the innovative lighting concept actually meets the needs of the users, the PTL was evaluated, considering the user's perspective, both in terms of technology acceptance and usability. For this purpose, a specific longitudinal, uncontrolled usability and acceptance field study was carried out in two European countries (Spain and Austria). After the field studies, various focus groups with field study participants were carried out. These special focus groups aimed to measure the impact of PTL on job performance and wellbeing of users and their acceptance of the technology and to gain a better understanding of the results of the field studies [15,27].

Field Studies

The field study was carried out as a longitudinal, uncontrolled usability and acceptance study on the premises of the IREC (Barcelona, Spain) and Bartenbach (Aldrans, Austria) between June and August 2020. During the study period, the use of the PTLs was not subject to any specifications or restrictions and the lighting settings could be freely adjusted and changed at any time. Manual interventions (e.g. switching scenes or switching off lights) were always allowed. The entire functionality of the devices was freely available for the entire duration of the study. Usage data from the PTL and the workplace were automatically collected from all participants over the entire period of use. In order to determine the acceptance rates for the PTL, the users were also asked about their acceptance and usability of the device using an online questionnaire based on the Technology Acceptance Model for Luminaires (TAM-LIGHT). A total of 8 people were included in the evaluation process.

Before the start of the study, all participants were fully instructed in the functions and operation of the PTLs. This also included the sensors used (especially the implemented camera system) and the associated data processing and storage. All participants signed a confirmation of their consent to participate in the study.

Field study factsheet

For a qualitative evaluation of the system usability, the collected usage data was automatically aggregated into certain parameters and simplified graphics in a factsheet that was individualized for each user. Since the key figures were calculated in real time, a web app was used to visualize the factsheets. Each factsheet contains clear information on the key features of the PTL's usage (**Figure 10**):

- User settings: For the task-related scenes, user preference settings were visualized, including the number of saved changes and the maximum scene retainment.
- Mode usage: The manual interaction with the PTL contained information on scene usage, daily on-off cycles, number of daily interactions, manual mode changes and switch-offs. In addition, information on the distribution of scene usage and scene deactivation behavior was provided.
- Light shower use: The use of the light shower scene was characterized by a number of usage reports including manual triggers as well as the total usage time of the scene.
- AI gaze detection: The output of the AI components for estimating the direction of gaze was based on the tracking time per day and the percentage of successful gaze assessments in these time periods. In addition, the results of the AI components were given for each task as a total task duration and a continuous task duration.
- Occupancy profile: As the PTL was used for automatic presence detection at the workplace, a complete presence profile could be created for each user.
- Usage profile: In order to make it easier to compare the test subjects, the person-related information was finally compared to the entire test group. For this purpose, five basic parameters were determined, which were transformed into ranges at group level. The individual was then localized based on the percentage of the individual value within the respective group area.

The information that could be obtained on the basis of the fact sheets was then made available as input for the focus groups.

Questionnaire

At the end of the study period, all participants were sent an online questionnaire with 34 questions in 5 different categories, in which they were asked to rate their subjective experiences with the PTL. The questionnaire contained questions in the following categories:

- Socio-demographic data: This part contained 9 questions to assess the relevant characteristics of the test group. Questions about age, gender, use of visual aids, and work and sleep times were included.
- Subjective impact assessment: This part contained 6 questions to assess the subjective perception of the effectiveness of the lighting on lighting-relevant

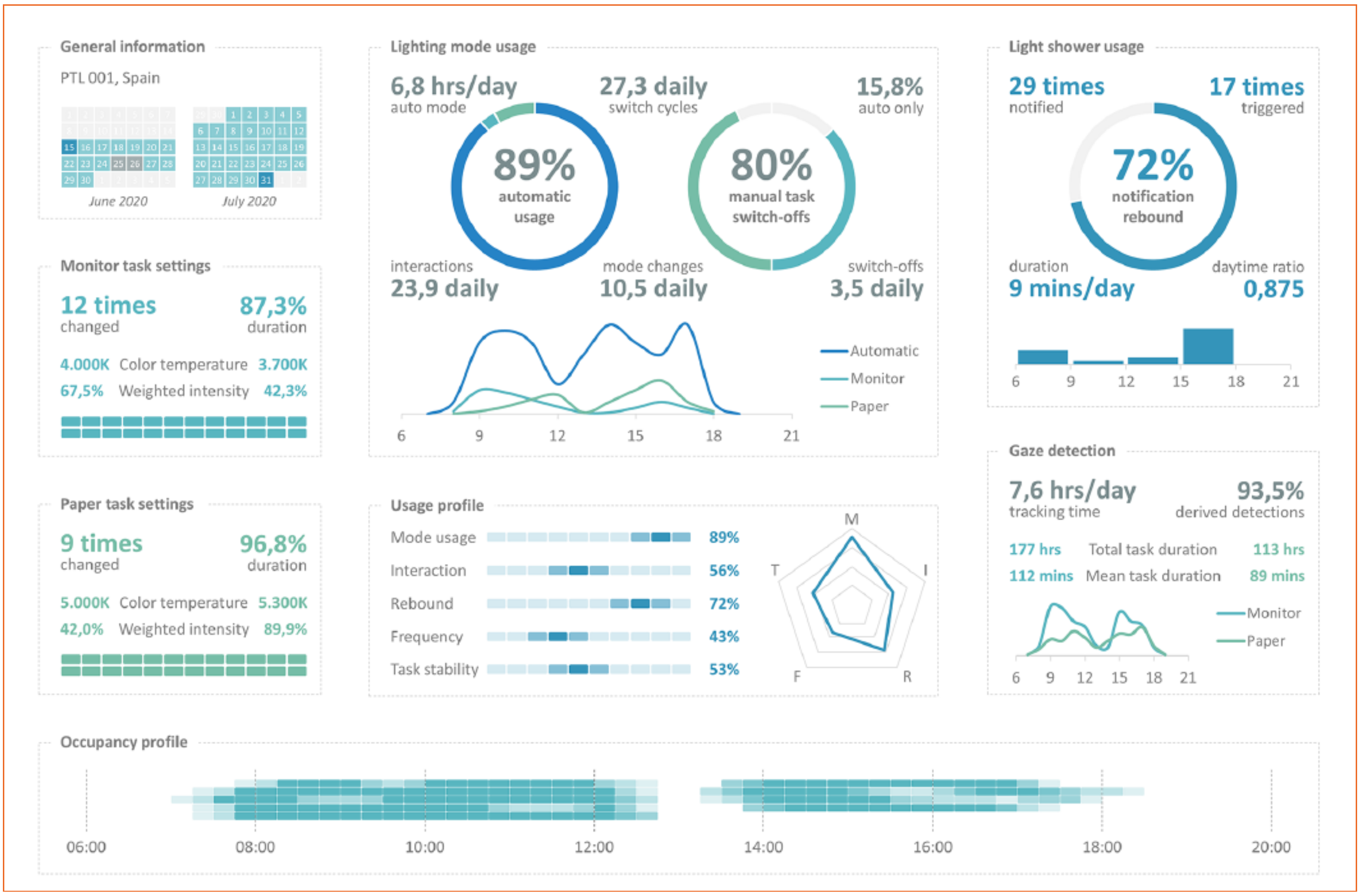

Figure 10: Automatically generated fact sheet of the user behaviour.

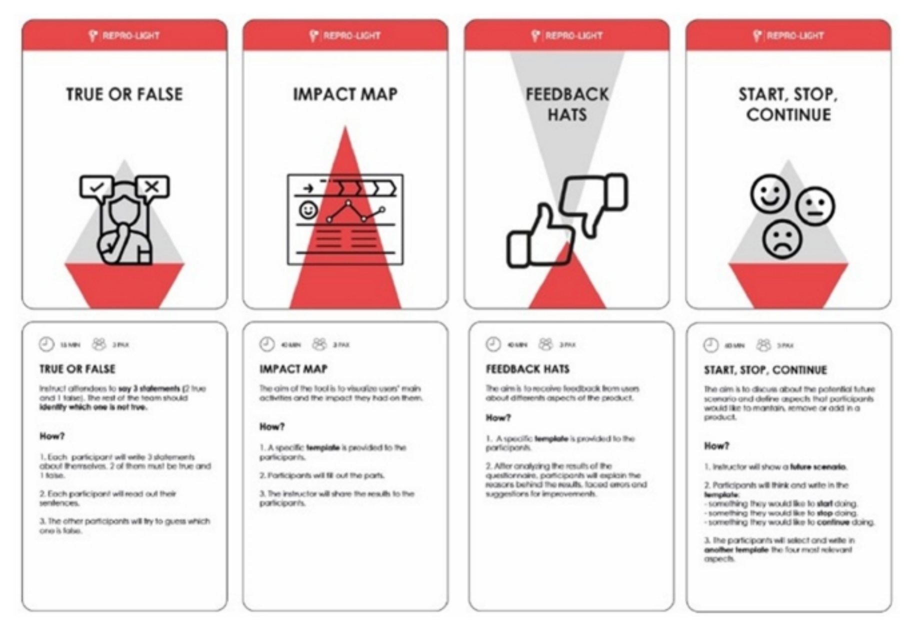

Figure 11: Visual cards of activities carried out during the focus groups.

parameters (e.g. sleepiness, performance and mood). All questions in this group were mapped on a 7-point Likert scale.

- System usability: This part contained 6 questions to evaluate the system usability. In particular, questions about the human-machine interface (control application) were in the foreground with questions about the simple understanding of the user interface and the underlying control logic. All questions in this group were mapped on a 7-point Likert scale.
- System acceptance: This part contained 10 questions based on the TAMLIGHT model in order to estimate the acceptance rates for various aspects of the control and system hardware. The focus was on both the core aspects of the developed lighting solution (rear wall, shadow, reflected glare) and the innovative technological implementations (camera system and AI, lighting control application). All questions in this group were mapped on a 7-point Likert scale.
- Overall assessment: This part contained 2 questions to assess the overall assessment of the development. Both the personal assessment and the recommendation potential of the PTL were queried. Both questions were mapped on a 10-point Likert scale.

All questionnaires were created with LimeSurvey Version 2.05+ [10] and filled out by the participants within one day of submission.

Focus Groups

To evaluate the customer's acceptance and satisfaction with the PTL, two different focus groups with the participants of the field study were held in Austria and Spain. The results of the field study have been used as a primary input, as the results of selected questions from the online survey and the data from the fact sheets was discussed in more detail. In particular, the focus group method should help to qualitatively discern reasons for the results of the field study and gain detailed insights in the opinions of the users towards the acceptance, the impact of the PTL on performance and wellbeing and its exploitation.

The workshop was structured into several phases, each supported by visual aids and templates (**Figure 11**):

- Icebreaking activity: To increase the overall group interactivity [16], the workshop was opened with a quick 10-minute icebreaker activity. During the so-called true and false activity, the moderator intended to energize participants and to tackle the meeting with enthusiasm. Each person was asked to brainstorm three "facts" about themselves - two of the facts should be true, and one should be a lie. Co-workers could take turns guessing which is the lie. This short game could help the team learn facts about one another, so they could begin forming deeper bonds.
- Feedback hat activity: During the feedback hats activity [17,18] the participants had 90 minutes to give feedback concerning the usability of the control, light quality, system acceptance and general impression of the PTL. Afterward the results were discussed on a group level and accompanied and collected by the moderator.
- Impact map: The impact map activity [19,20] aimed to investigate whether the PTL system had an impact on the work performance and well-being of the users compared to their previous lighting system. It incorporated the discussion of individual impressions on a group level and lasted 45 minutes.
- Start, stop, continue: Finally, during the Start, stop, continue activity [21] participants were asked to define aspects that they would like to maintain, remove from or add to the PTL. The participants collected aspects of these three categories in 10 minutes. Then the individual ideas were discussed in a 30-minute time slot within the group.

Results

In relation to the essential characteristics of the PTL, the results show that trust in the PTL is very high, the general disruption from the real wall is low, but context-dependent, and users prefer the use of modern, ICT-based light controls over classic control elements. Most users would keep using the PTL and would even highly recommend it to a friend or colleague.

When analysing the main aspects associated with the acceptance rates, the PTL achieved better results in all aspects compared to current solutions installed in the workplace. PTL users are more aware of the effects of light on their general wellbeing and individual work performance. In addition, the PTL functions enable the user to adapt the light at the workplace to their personal preferences and to change the settings of the luminaire more easily thanks to the intuitive design of the control application.

The features particularly emphasized by the users, however, are the functions of personalization, individual adjustment, automatic presence detection and the light shower. In this sense, the results of the focus groups were a valuable addition to review the results of the PTL that had already been collected and were used to compare and discuss these aspects, to receive feedback and interesting ideas for improvement. Therefore, the results show that the main aspects of PTL have a positive impact on overall technology adoption and user well-being.

Evaluation in Laboratory Studies

Two laboratory studies were conducted in addition to these field studies.

Study A: Young, Healthy Workforce

Aim: Quantification of short-term light effects

In a pre-study, effects of three different light interventions were evaluated. First, a regular, 20-minute bright light intervention ($E_v = 1300$ lx at eye level; "Light Shower"), second, a condition with constant, blue-enriched light (**Figure 7**), and third, a Standard light setting ($E_v = 200$ lx at eye level). Participants took part in the study on three different days for five hours each. Every hour, the visual Psychomotor Vigilance Task (PVT) was administered for 15 minutes, followed by several questionnaires. The PVT is a reaction time test and is commonly used as a measure of vigilance (22; 23).

Highest vigilance (PVT score) was found in the Light Shower condition, lowest vigilance in the blue light condition (**Figure 12**).

Self-assessed performance was rated highest in the Light Shower condition (**Figure 13**).

Based on this study, the study design was revised to further explore possible short-term light effects, and a new main study was subsequently conducted. The blue light condition was not included in the main study and the Standard setting was modified into a Placebo light intervention. The Placebo light intervention was designed to make it seem to participants as if they were receiving a bright light intervention (Light Shower). To achieve this, output of the PTL was first reduced to 50% of the Standard setting ($E_v = 200$ lx) over the course of 30 seconds (unnoticeable). Subsequently, output of the PTL was increased to 50% of the Light Shower setting over the course of 15 seconds (noticeable, imitating a light "shower"). Afterwards, the PTL was dimmed back down to the Standard setting very slowly over 3.5 minutes (unnoticeable). Participants perceived this as if they were receiving a Light Shower, while they were actually only receiving about half of the light dose at the brightest phase of the Placebo intervention.

The study was conducted as a 5-hour laboratory study on 2 consecutive days from early morning until noon. Cognitive tests and questionnaires were administered every hour (1 hour = 1 testing period). Subjective sleepiness was rated on a scale from 1-5 before and after the auditory PVT (aPVT). 58 participants took part in the study, with age ranging from 18-50 years.

Research questions:

- Can acute stimulating effects be achieved through regular 30-minute bright light interventions ($E_v = 1300$ lx; called "Light Shower", abbreviated "LSH") compared to a Placebo light intervention ("PLA")?
- Does the PTL have an influence on visual performance parameters?

Since data analysis for this study is still ongoing, only preliminary results are reported in this article. These results can be summarized as follows:

- Significantly higher vigilance (aPVT score)

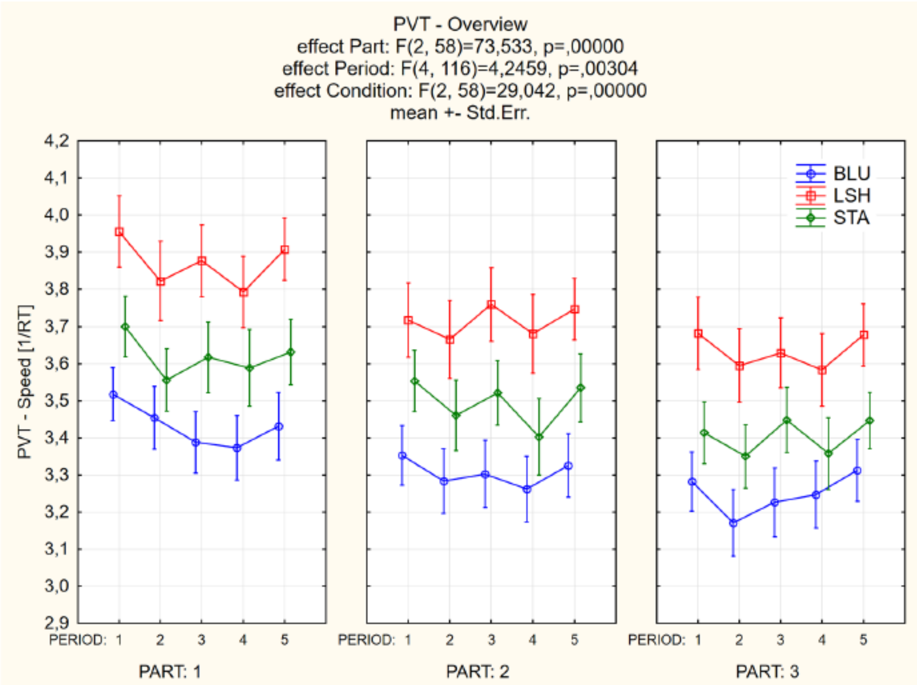

Figure 12: Results of the PVT. Part 1, 2 and 3 correspond to the first five, middle five and last five minutes of the test.

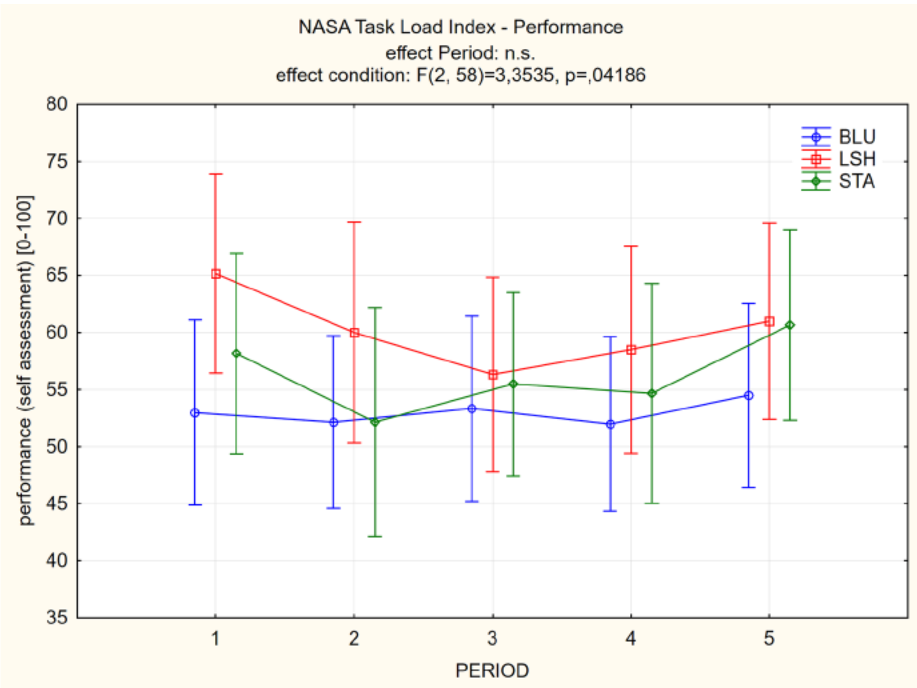

Figure 13: Results of the NASA Task Load Index Performance Scale.

in the Light Shower condition, especially at the end (after 5 hours); **Figure 14**

- Main effect of Condition: $F(1,57) = 4.161$, $p = 0.046$, ${\eta_p}^2 = 0.068$
- Main effect of Period: $F(2.9, 165.6) = 1.923$, $p = 0.130$
- Interaction effect of Condition * Period: $F(3.1, 180.4) = 4.280$, $p = 0.005$, ${\eta_p}^2 = 0.070$

- Sleepiness (rated from 1-5) significantly increases with short-term workload (15 min auditory PVT) in both conditions, but tends to be slightly lower in the Light Shower condition; **Figure 15**
  - Main effect of Condition: $F(1,57) = 1.028$, $p = 0.315$, ${\eta_p}^2 = 0.018$
  - Main effect of Period: $F(3.1, 176.5) = 8.095$, $p < 0.001$, ${\eta_p}^2 = 0.124$
  - Main effect of Time of Measurement (ToM): $F(1,57) = 38.041$, $p < 0.001$, ${\eta_p}^2 = 0.400$
  - Interaction effect of Condition * Period: $F(3.4, 195.3) = 0.644$, $p = 0.608$
  - Interaction effect of Condition * ToM: $F(1,57) = 2.056$, $p = 0.157$
  - Interaction effect of Period * ToM: $F(3.5, 199.6) = 4.258$, $p = 0.004$, ${\eta_p}^2 = 0.070$
  - Interaction effect of Condition * Period * ToM: $F(3.8, 217) = 3.112$, $p = 0.018$, ${\eta_p}^2 = 0.052$
- No significant impairment of visual performance (visual acuity) in the Light Shower condition ($F(1,56) = 0.443$, $p = 0.509$)
- No significant increase in asthenopic complaints in the Light Shower condition ($F(1,42) = 0.006$, $p = 0.941$)

As can be seen in **Figure 14**, while both conditions have similar aPVT Speed in Period 1, aPVT Speed significantly increases over the next hours in the Light Shower condition. In the Placebo condition, aPVT Speed roughly stays the same. Differences between LSH-1 and LSH-5 as well as LSH-5 and PLA-5 are significant ($p < 0.001$ and $p = 0.019$, respectively).

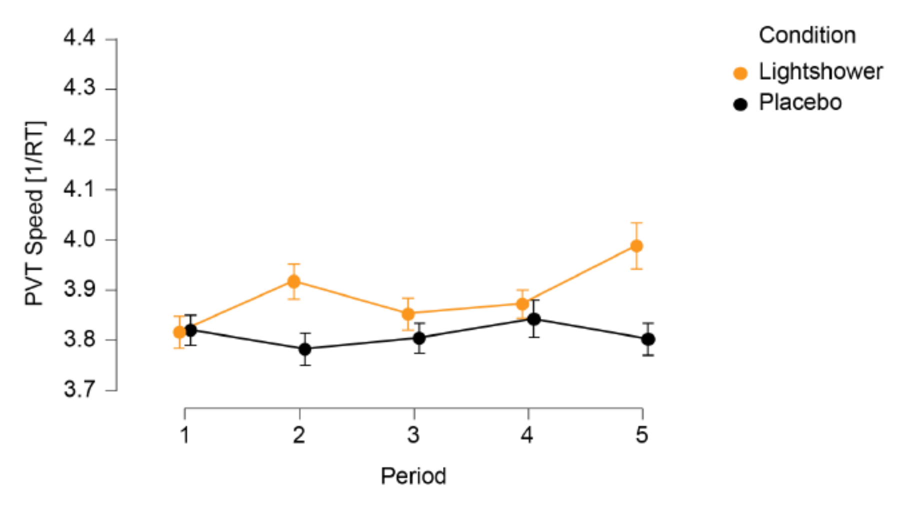

Figure 14: Results of the aPVT (Auditory Psychomotor Vigilance Test).

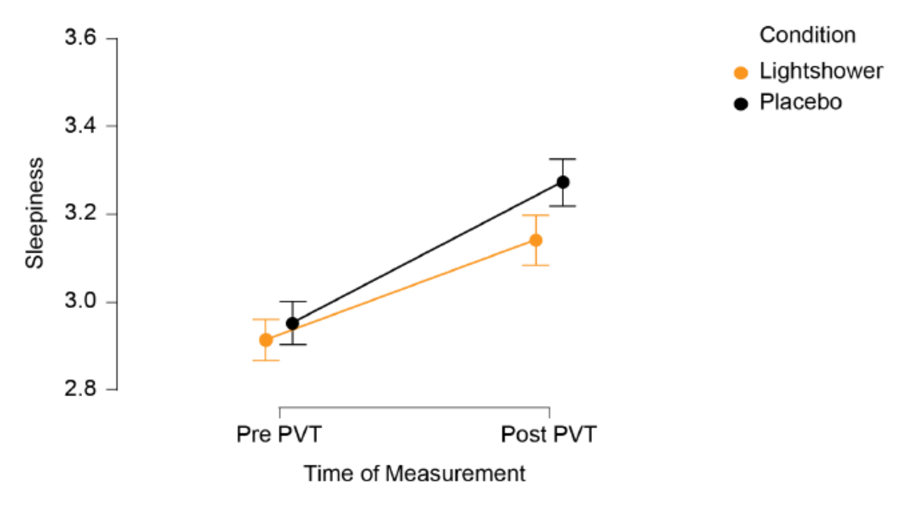

Figure 15: Change in Sleepiness before and after the Auditory PVT.

While sleepiness increases significantly in both conditions, the mean increase tends to be slightly lower in the Light Shower condition ($mean_{PLA} = +0.32$, $mean_{LSH} = +0.23$), although the difference in Post PVT between the two conditions is not significant ($p = 0.294$).

Data analysis for this study is still ongoing and results are subject to change. The final results, including heart rate variability data, additional cognitive tests and questionnaires, will be published in a future article.

Study B: Older, Partially Visually Impaired Workers

Aim: Improving visual performance through personally preferred lighting conditions (32 older, partially visually impaired participants)

Research questions:

- How great is the variation in preferred light settings at the workplace among older workers?
- Do personally preferred lighting settings have a positive influence on visual performance?

The results of study B (older and partially visually impaired office workers) are:

- There is an extremely large variation in the preferred light settings at the workplace among older workers (**Figure 16**)
- Preferred intensities at desk and wall are very high (> 2000 lx, (**Figure 16**)
- Mean CCT = 3800 K, Mean $E_v = 800$ lx
- Higher satisfaction with light settings; support from lighting better perceived
- Improved visual performance (BRV on paper); (**Figure 17**)
- No significant asthenopic complaints
- Individualized lighting increases acceptance, satisfaction, and performance.

Acknowledgements

*The Repro-light consortium consisted of leading European experts, including TRILUX, a driving force in the European lighting industry, component manufacturers such as BJB, Grado Zero Espace and Rohner Engineering, innovative members of the lighting industry such as Bartenbach and Luger Research, as well as experts in lighting sustainability and life cycle assessment (IREC) and the University of Mondragon, leaders in the social sciences (**Figure 18**). This project was funded by the European Union's Horizon 2020 research and innovation program under grant agreement No. 768780.*

Summary

The experiences and results of the project can be summarized as follows:

- The transition of the lighting industry to a circular economy is only at the very beginning, especially the raw material and waste management.
- For a meaningful Life Cycle Analysis (LCA) of luminaires and lighting solutions, some necessary data and standardized procedures are currently still lacking; in particular, the fate of electronic scrap is unclear.
- Personalized lighting solutions are strongly desired by the user, and there is a large variation in the individual needs. Individualized lighting improves acceptance, satisfaction and performance, and most likely also health in the long term.
- Applying a 30-minute bright light ("light shower") creates acute effects like higher vigilance and better resilience; but this needs further research to trade up these effects with the additional investments. ■

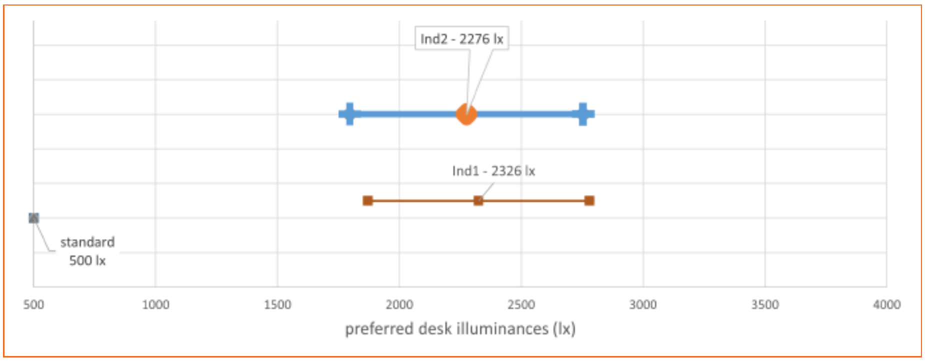

Figure 16: Preferred Illuminances at the desk Emean = 2300lx (2 adjustments by each test person).

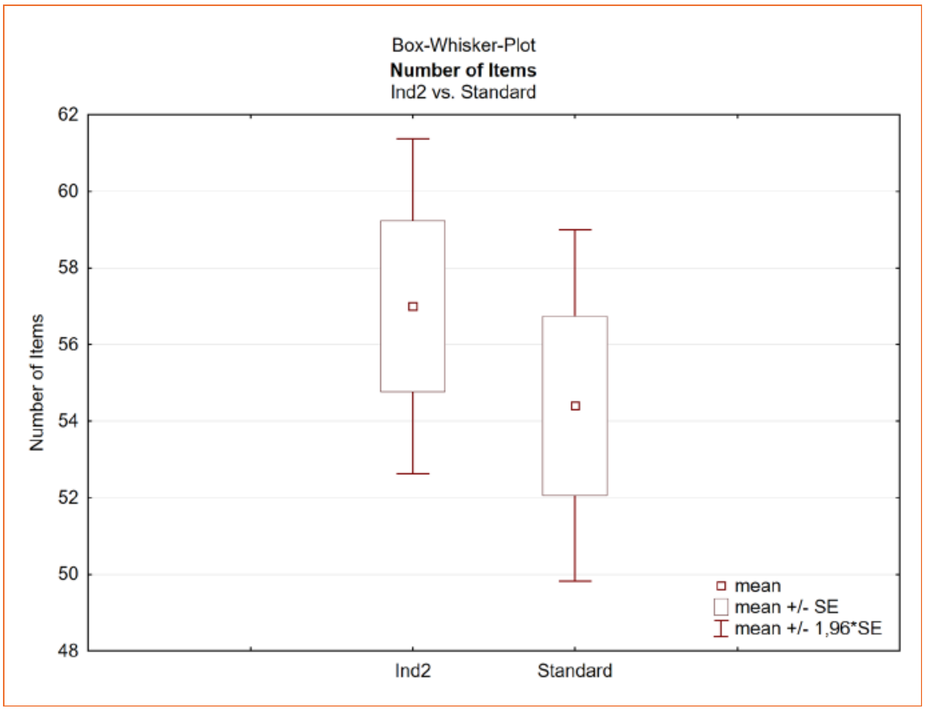

Figure 17: Results of the BRV (Letter-Row-Comparison Test); Ind2 = Scene set individually, Sta = Standard condition with $E_h = 500$ lx; significance $p = 0.005$.

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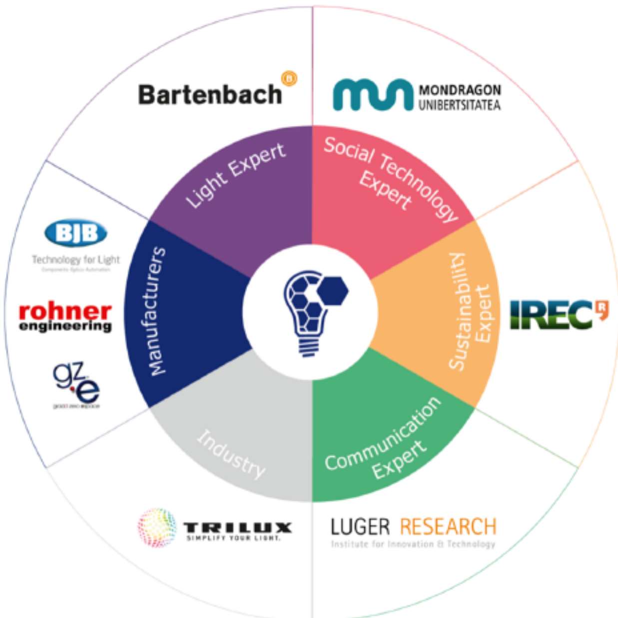

Figure 18: Repro-Light Project Consortium [1].

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References

[1] Repro-Light. [Online] 2018. https://www.repro-light.eu/ bzw. https://twitter.com/Reprolight.
[2] Ferreira, Víctor et al. On Life Cycle Assessment to Quantify the Environmental Impact of Lighting Products. LED professional review (LPR). Sep-t/Oct 2019.
[3] Agenzia Fides. [Online] http://www.fides.org/de.
[4] UNEP / SETAC. Life Cycle Management – A business guide to sustainability. Paris : s.n., 2007.
[5] OECD. Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences. Paris : OECD Publishing, 2018. https://doi.org/10.1787/9789264307452-en.
[6] Umwelt Bundesamt . [Online] https://www.umweltbundesamt.de/daten/energie/primaerenergieverbrauch.
[7] Repro-light: Die Leuchte der Zukunft - nahchaltig in Produktion und Nutzung. Pohl, Wilfried and Weninger, Johannes. online : Licht2021, 2021.
[8] General, European Commission: Secretariat. Communication on the European Green Deal. 2019. COM (2019) 640.
[9] Future luminaire Design: Conclusions from the Research Project Repro-light. Sebastian Knoche, Horst Rudolph. online : LpSDIGITAL, 2020.
[10] Schmitz, C. LimeSurvey: An open source survey tool. [Online] LimeSurvey Project Hamburg, Germany, 2012. http://www.limesurvey.org.
[11] A European Workplace Lighting Survey. Ganix Lasa et al. Bregenz : LpS/TiL, 2019.
[12] The majority of Europeans want better workplace lighting. [Online] https://www.repro-light.eu/the-majority-of-europeans-want-better-workplace-lighting.
[13] Bartenbach GmbH. Personal Table Light. [Online] 2020. https://www.youtube.com/watch?v=XdYouJsOV7U.
[14] Park, Seonwook, Spurr, Adrian and Hilliges, Otmar. Deep Pictorial Gaze Estimation. s.l. : Proceedings of the European Conference on Computer Vision (ECCV), 2018.
[15] Measuring the user acceptance: User-centered Methodes and Co-creation Processes in Luminaire Development. Lasa, Ganix et al. online : LpSDIGITAL, 2020.
[16] Almethhib, M. M. The Impact of Ice Breaking Exercises on Trainees' Interac-tions and Skill Acquisition: An Experimental Study. Economics and Administration. 23 (1), 2009.
[17] Edward de Bono. Six thinking hats. London : Penguin Life, an imprint of Penguin Books, 2017. 9780241257531.
[18] Gill-Simmen, L. Developing critical thinking skills: Using Edward de Bono's six thinking hats in formative peer assessment & feedback. Journal of Applied Learning and Teaching. 2020, Vol. 3, 1.
[19] Chang, S. Hsu and Ming-Chuen Chuang and Chien-Cheng. A semantic differential study of designers' and users' product form perception. International Journal of Industrial Ergonomics. 2000, Vol. 25, 4, pp. 375-391.
[20] Yuexiang Huang, Chun-Hsien Chen, Li Pheng Khoo. Products classification in emotional design using a basic-emotion based semantic differential method. International Journal of Industrial Ergonomics. 2012, Vol. 42, 6, pp. 569-580.
[21] Hoon, A. and Oliver, E.J. and Szpakowska, K. and Newton, P. Use of the 'Stop, Start, Continue' method is associated with the production of constructive qualitative feedback by students in higher education. Assessment and evaluation in higher education. 2015, Vol. 40, 5, pp. 755-767.
[22] Thomann, Janine, et al. Psychomotor Vigilance Task Demonstrates Impaired Vigilance in Disorders with Excessive Daytime Sleepiness. Journal of Clinical Sleep Medicine. 10, 2014, Vol. 9, pp. 1019-1024.
[23] Smolders, Karin C. H. J. and de Kort, Yvonne A. W. Bright light and mental fatigue: Effects on alertness, vitality, performance and physiological arousal. Journal of Environmental Psychology. 2014, Vol. 39, pp. 77-91.
[24] Additive Production: New Disruptive Fabrication Technologies for a Novel Design Approach. Cozzoni, Enrico, Espace, Grado Zero and Pucci, Claudio. online : LpSDIGITAL, 2020.
[25] Future Scenarios of the Lighting Industry: Towards a More Sustainable and Innovative Market. Lasa, Ganix, Gonzales, Itsaso and Mazmela, Maitane. online : LpSDIGITAL, 2020.
[26] About Optical Possibilities - How LLT (LensLightTile) Technology Might Change Lighting Products. Pohl, Wilfried. online : LpSDIGITAL, 2020.
[27] Repro-light — Following a User-centered Design Approach to Develop the Luminary of the Future. Lasa, Ganix. 77, s.l. : LED professional, 2020. 1993-890X.
[28] Ferreira, Victor et al. On Life Cycle Assessment to Quantify the Environmental Impact of Lighting Products. LED professional review (LPR). 2020.

Disinfection with UV-C LED and Optics Technologies

A distinct opportunity is materializing for UV-C LED-based solutions to deliver effective disinfection in a wide variety of facilities. Although the technology is proven, bringing safe and competent products to the marketplace requires expertise and support from all stakeholders, including research institutes, LED manufacturers, LED optic specialists, LED module solutions providers, and system integrators. After all, there are many variables to consider, not least LED output power, irradiation levels, time, geometry, and the type of targeted organisms. This article details the latest solutions and way forward for UV-C LED-based disinfection, as well as its benefits and application opportunities.

In simple terms, UV radiation's disinfection properties result from the dividing of chemical bonds between nucleic acids in the DNA of the virus or bacteria. Due to the subsequent formation of thymine dimers, DNA duplication becomes impossible during the cell division process.

Achieving effective damage to the DNA of the virus or bacteria is dependent upon factors that include radiation wavelength, the acting dose, and the sensitivity of different pathogens to UV-C. By way of example, it is relatively simple to inactivate staphylococcus and E. coli, but SARS-CoV-2 (which leads to COVID-19) demands a dose that is some 5-17 times higher, according to various studies referred to by the Fraunhofer Institute.

UV-C LEDs vs. Mercury Lamps

The range between 260 nm and 270 nm is the optimum disinfection efficiency of UV-C LEDs for the inactivation of micro-organisms. An important advantage is that LEDs can be manufactured in different wavelengths and distribute emission energy over a wide wavelength range. Conversely, low-pressure mercury lamps only offer a narrow, fixed-emission wavelength of 254 nm.

LEDs and their potential to begin disinfecting without any warm-up phase provides another advantage. Full power is available immediately, making UV-C LEDs perfect for applications where timed on/off operation is necessary. In contrast, it takes a few minutes for mercury lamps to attain full output performance. It is also worth noting that LEDs can be pulsed for higher output and, unlike mercury lamps, are suitable for dimming from 0-100%, making them ideal for disinfection tasks that require variable intensity.

High irradiation intensity at close range is a further benefit of UV-C LEDs. As a result, high array density is achievable (using appropriate cooling - water can be deployed as a coolant for UV-C LEDs). The use of lenses or reflectors for beam shaping is also possible, focusing radiation energy on the target surface.

Another advantage is that UV-C LEDs are completely ozone-free because they have no wavelengths less than 240 nm. Ozone is an undesirable irritant gas.

Finally, whereas mercury lamps present a certain fragility due to their risk of glass breakage, LEDs (not containing mercury) offer high mechanical stability, making them ideal for mobile applications that demand shockproof and/or waterproof characteristics.

Target Applications

There are many market disinfection opportunities for UV-C LEDs, largely focusing on four principal areas: surface, HVAC, water and biomedical.

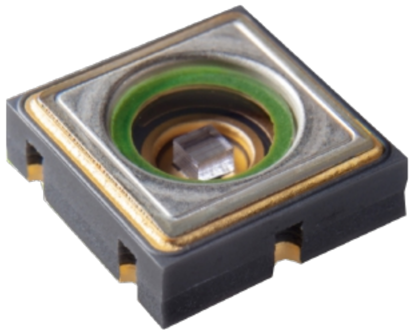
The current focus of most UV-C LED developers is surface disinfection, mainly due to the specific advantages this technology offers, like zero on/off time and form factor. Applications in the HVAC arena differ from surface disinfection tasks in that there exists the potential to apply UV-C LED solutions within the enclosed design of the system. Inherently, there is less concern about the exposure of humans to radiation.

Maybe offering the most significant potential for UV-C LED-based solutions is the water segment. A worldwide necessity for effective disinfection products exists as many regions of the planet are still unable to access clean drinking water. There are many new developments and ideas emerging that will help optimize UV-C LED solutions for water disinfection. The constant demand for innovative solutions to disinfection is also prevalent in biomedical facilities, such as hospitals, clinics, and research laboratories.

Current and Future Solutions

A number of proprietary UV-C LED solutions are available today, including a mid-power 17.5 mW product cased in a 3.5 mm x 3.5 mm package and a high-power 70 mW product measuring 6.8 mm x 6.8 mm. Looking to the near future, a high-power UV-C LED in a 3.5 mm x 3.5 mm package is currently in development, as is a super high-power 4-in-1 package (**Figure 1**).

At present, the leading-efficiency UV-C LED delivers a peak wavelength of 280 nm and an output of 70 mW at 350mA. However, the quality and reliability of this particular product means users can drive the current up to 500mA. In turn, it is possible to achieve output of approximately 100 mW from just one LED chip. The 280 nm UV-C LED comes in a hermetically sealed package for superior lifetime and reliability at high temperatures and humidity. A hermetic shield is important when deploying UV-C LEDs in demanding environmental conditions. It protects the LED, and the LED die from the potentially damaging effects of moisture, condensation and corrosive gases (**Figure 2**) [1].



Peak Wavelength	280nm
Input Power (I_F)	1.9W (350mA)
Radiant Flux	70mW
V_F	5.5V
Efficacy	3.6%
Reliability	Major Advantage

Figure 2: 70 mW High-Power UV-C LED package with the main technical parameters (Nichia's NCSU334B).

Tests demonstrate the critical nature of hermetic sealing. Under demanding conditions of 60 °C ambient temperature and 90% relative humidity, a proprietary UV-C LED with hermetic shielding still delivers circa 85% flux intensity after 8,000 hours of operation. However, the flux intensity of a product with a non-hermetic shield drops to approximately 40% after just 6,000 hours.

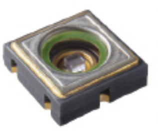
	6.8x6.8mm PACKAGE	3.5x3.5mm PACKAGE
SUPER HIGH POWER	UPCOMING 4-IN-1 PACKAGE	
HIGH POWER	 NICHIA NCSU334B 280nm 70mW Flux 1.9W Input Power	UPCOMING
MIDDLE POWER		 NICHIA NCSU434A 280nm 17.5mW Flux 0.5W Input Power

Figure 1: Power/Package matrix of UV-C LEDs (Nichia).

Sterilization

Whereas traditional UV-C technologies like low-pressure mercury vapor lamps are limited to a peak wavelength of 254 nm, the most efficient wavelength to disinfect bacteria and viruses is established as 260 nm, as a result of the DNA/RNA's peak absorption spectrum.

However, 280 nm delivers the highest virucidal power as it has exceptionally strong irradiance, wall-plug efficiency and lifetime in practical operating conditions. Indeed, data highlights that the virucidal power of the 280 nm LED is approximately 1.3 times (127%) that of 265 nm LEDs.

That 280 nm UV-C LEDs provide flux intensity of 92% after 4,000 hours, compares favorably against 265 nm alternatives (67% after 4,000 hours). Additionally, 280 nm remains highly effective for sterilization, as confirmed by independent third-party test data.

Looking ahead, it may become feasible to introduce the levels of reliability and quality associated with the proprietary 280 nm UV-C LED to a lower wavelength, but the 280 nm solution remains optimal at present.

Optics

Deploying optics permits users to shape the energy emitted by a UV-C LED, delivering concentration to areas in most need, an effect that also aids energy conservation.

LEDiL has introduced the world's first standard optic family specifically for use with UV-C LEDs. Violet [2], as the solution is called, features a superior type of silicone (instead of traditional quartz glass) to help achieve high UV transmittance rates (80%) and the generation of more cost-effective solutions without restrictions on shape. To ensure all materials can withstand long-term UV-C use, the lens is secured in place using a stainless-steel frame. Presently, three beam types are available, extending from a 60° wide beam to a 14° spot beam.

To reveal the positive impact of optics, a recent test scenario involved nine ceiling-mounted luminaires suspended 4.5 m above a 3 m x 3 m target area, where each luminaire comprised four modules. Using solely UV-C LEDs, the tests showed an average irradiance of 119 mW/m^2. However, irradiance increased to an average of 258 mW/m^2 when complementing the LEDs with optics. In practical terms, as this figure is more than twice the intensity of bare LEDs, the user could either reduce the time required for surface disinfection by 50% or use fewer LEDs to save costs (**Figure 3**).

Upper-Air UVGI

Another important application for optics is upper-air UVGI (UV germicidal inactivation), which concerns the disinfection of air in the space between the ceiling and heads of people in an occupied room.

The principles of the process are fairly simple, with warm contaminated air ascending into the disinfection zone, and cool clean air descending. Optics use UV irradiation to ensure it remains in the upper ceiling portion of the room, safeguarding occupants.

Of course, there are limits on the quantity of UV applied in upper-air UVGI applications. The limit is currently 0.4 μW/cm^2 for an exposure time of 8 hours. In UVGI trials based on optics featuring a 14° beam (80% efficiency) and 280 nm LEDs, the beam stayed focused on the upper portion of a room while generating a maximum irradiance of 0.3 μW/cm^2 (**Figure 4**).

Real Life UV-C Module

Lumitronix has successfully combined optics and UV-C LEDs into a ready-to-use module for the decontamination of surfaces. There are 12 280 nm UV-C LEDs on the module, complemented by optics, providing a total optical power of 630 mW [3].

In terms of advantages, the use of LEDs renders it possible to dose the electric power to an absolute minimum, making modules of this type ideal for battery-driven applications. Importantly, a proprietary software-based security system prevents harmful UV-C exposure. Based on a three-layer safety concept, the system comprises a motion sensor within the room, a button connected to the door, and a pushbutton located outside the room to trigger the UV-C fixtures manually. It is only permissible to activate the external pushbutton if the door is confirmed as closed and no motion is detected inside the room. If one of these conditions changes, the UV-C LED turns off instantly.

To highlight the module's effectiveness, a simulated test case involved a doctor's office, which measured 2.5 m high and occupied a floor space of 4 x 5m. Within the office were an instrument table, treatment couch, cupboard, and desk. A non-optimal arrangement of furniture was purposely selected to demonstrate the differing extent of surface disinfection results. The test sought to answer two questions: how much optical power would reach the surfaces from four modules installed on the ceiling, and how long would it take to inactivate viruses and germs?

The instrument table and treatment couch - the most critical surfaces as they come into patient contact - exhibited promising results, with irradiation times for SARS-CoV-2 of around 12 and 20 minutes respectively. The simulation also revealed the importance of optimum light source placement, as a shadow effect thwarted the safe disinfection of the cupboard and desk. As the proprietary module can be customized for different power outputs, beams and layouts, the huge benefit of LED-technology is clear to see in terms of design flexibility.

Building the Application

The application builders' role should not be underestimated as these companies have in-depth knowledge of UV curing and disinfection, and can leverage this expertise to select the most advantageous and optimal UV-C source for each project.

To achieve disinfection, dose is the most critical factor, although time is often more important for end users. It is possible to calculate the dose by multiplying the irradiance by time. However, it should be noted that irradiance is impacted by several variables, such as the source, the size of the area it has to reach, and the distance involved.

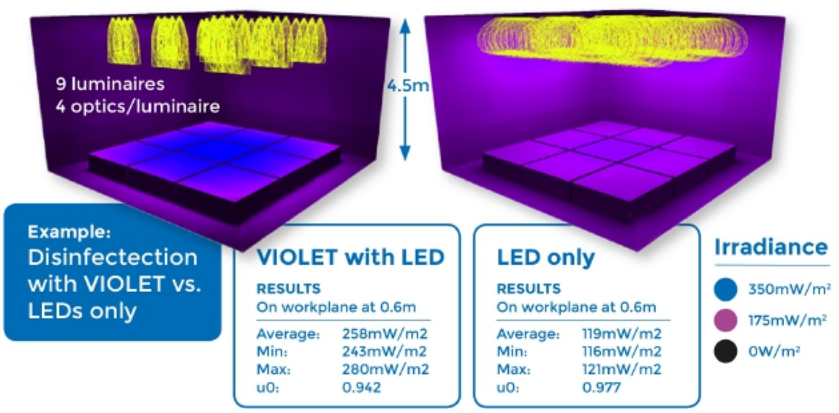


Figure 3: Comparison of UV-C disinfection parameters with and without optical devices (Nichia/LEDiL).

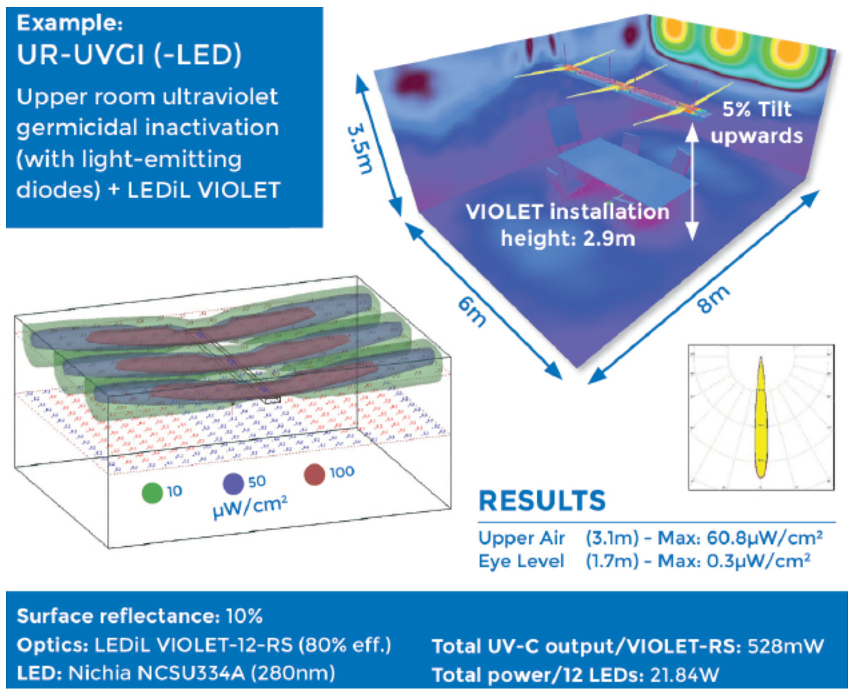


Figure 4: Upper-Air UVGI disinfection results for a 6 m x 8 m room with UV-C LEDs and UV-C optics (Nichia/LEDiL).

According to application builder Efsen, surface disinfection solutions are likely to take many different forms soon, including UV-C wands, bars, benches and towers, with selection dependent on the amount of time commercially permissible to achieve disinfection. Existing UV-C LED solutions are already proving ideal for small and narrow applications like payment terminals, and some of these products can also be competitive for larger areas and surfaces, unless time is a constraint.

Moving forward, the market will almost certainly experience an increase in LED output, making more applications accessible to UV-C LEDs. Whatever the design configuration, the emergence of regulations will be important to avoid the market becoming populated with solutions that are unsafe and/or unfit for purpose. ■

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Working in the lighting industry for over a decade, Jonatan Klee is a key account manager at Nichia responsible for the company's UV-LED business in Europe. His current focus is to develop the UV-C LED market and apply Nichia's proprietary technology to existing and new applications. In the past, Jonatan was responsible for spearheading growth in LED sales and product development. He has over 5 years of specific experience with the UV-LED segment and related applications.

References

[1] Nichia's UV LEDs https://www.nichia.co.jp/en/product/uvled.html
[2] LEDiL's UV-C Optics https://www.ledil.com/news_all/violet-silicone-optic-for-uv-c-applications/
[3] Lumitronix's UV-C Module https://www.leds.de/violet-uvc-led-modul-280nm-12-nichia-leds-297-3-x-44-6mm-48v-630mw-37199.html

Influence of UVC LED Disinfection on Polycarbonate Materials

Advertorial: Covestro LLC, Crystal IS

The invention of LEDs that generate germicidal deep-ultraviolet (UVC) light has driven advances in surface disinfection. This study explored how UVC disinfection influences polycarbonate-based plastics, commonly used to make medical equipment, car interiors, and consumer electronics, by exposing them to light from UVC LEDs equivalent to thousands of disinfection cycles. Our test results showed that physical properties like strength and heat resistance were fully retained after UVC exposure. White-colored materials turned yellow, black-colored materials showed essentially no color shift, and in all cases the surface finish was preserved. The color shift was essentially the same whether the samples were irradiated at high or low intensity, or in a continuous or intermittent fashion. UVC-induced color changes appeared to penetrate no more than several micrometers below the part surface. While they may change color, polycarbonates seem well-suited to applications where they will be repeatedly disinfected by UVC light.

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Introduction

With the growing effort to fight transmission of infectious diseases, there's great interest in finding more effective and convenient ways to disinfect surfaces. Deep-ultraviolet (UVC) light is one alternative to chemical disinfection. UVC is an established technique for disinfecting drinking water and purifying air that is now finding increased use in sanitizing surfaces for products like medical equipment, car interiors, and consumer electronics.

While UVC-emitting fluorescent bulbs have been available for decades, recent advances in semiconductor technology have driven the development of high-performance LEDs built to deliver UVC light at precisely the wavelengths with the most potent germicidal effect: 260–270 nm. UVC bulbs continue to be popular for purification equipment, but the small size, versatility, and energy efficiency of UVC LEDs gives designers exceptional freedom to design innovative new disinfection systems.

Because surface disinfection using UVC is new, relatively little is known about the effect of UVC light on materials. Plastics used in hospital equipment, car interiors, and personal handheld devices may benefit from periodic disinfection. Among the most common materials used for these types of equipment are polycarbonates, which are premier engineering thermoplastics with a unique combination of strength, impact resistance, heat resistance, and versatility and consistency in manufacturing, combined with a moderate price. The purpose of this study was to better understand how polycarbonate materials behave after exposure to UVC doses used for disinfection.

The UVA and UVB radiation from sunlight cause polycarbonates to yellow and degrade over months and years of outdoor exposure, as is the case with many plastics. UVC radiation is fully absorbed by Earth's atmosphere, so its effect on polycarbonate properties is not well understood. Because polycarbonate absorbs very strongly at UVC wavelengths, UVC light is not expected to penetrate nearly as deeply into surfaces as UVA and UVB light do. The shallow penetration depth of UVC could have a protective effect on polycarbonate parts. Two studies using very high doses of UVC light showed good long-term property retention in a polycarbonate [1] and a PC/ABS blend [2], demonstrating the suitability of polycarbonate-based materials even in applications where they reside very close to UVC lamps.

Experimental

We chose a total fluence (dose) of 120 J/cm^2 to approximate a lifetime of UVC disinfection cycles for a plastic equipment housing. The appropriate fluence depends on how often a part is disinfected, its service life, and the UVC exposure of each disinfection cycle. The dose of UVC required to kill microorganisms with a given effectiveness has been compiled for a wide range of species [3]. A fluence of 120 J/cm^2 represents 6,000 cycles at a typical disinfection dose of 20 mJ/cm^2, or 4,000 cycles at a more thorough 30 mJ/cm^2 dose, applicable to parts that are disinfected several times per day over the course of several years.

Application Area	Product Name	Color
Electrical and Electronic Equipment	Bayblend® FR3010 012622	White
	Makroblend® EL700 012772	White
	Makrolon® RW2407 010226	White
Medical Devices and Equipment	Bayblend® M301 FR 013771	White
	Bayblend® M850 XF 013771	White
	Makrolon® Rx1805 013771	White
	Makrolon® 2458 013184	White
	Makrolon® 2458 550115	Clear
	Makrolon® 2458 704363	Gray
	Makrolon® 2458 901528	Black
Automotive Interiors	Bayblend® T85 HD 901510	Black
	Bayblend® T85 XF 901510	Black

Table 1: Materials used in this study.

The materials chosen for this study are listed in **Table 1**. Various polycarbonate grades and polycarbonate blends in applications ranging from electrical equipment, medical devices and automotive interiors were studied. Further product information is available at `https://www.solutions.covestro.com`. Test specimens were injected molded per datasheet recommendations and physical properties were measured using ISO standard test methods. Color of rectangular plaques was assessed using a HunterLab UltraScan PRO diffuse sphere spectrophotometer using the CIELAB color space per ASTM E313 with D65 illumination and 10° observer, with additional kinetic measurements assessed using a PCE Instruments PCE-CSM 2 handheld specular 45°/0° color meter.

Materials were exposed to radiation from Klaran® LE Series UVC LED light engines, manufactured by Crystal IS. The peak emission is near 265 nm and the full width at half maximum is about 12 nm. UVC 9-LED light engines were assembled into vented light boxes and the intensity was measured by a Gigahertz Optik X1-1 optometer. Test specimens were placed within a defined area where the illumination was demonstrated to be near-uniform. Intensity was tuned by adjusting the distance from the LEDs to the test specimens, in the range of 0.10–0.35 W/cm^2 (1–3.5 W/m^2). At 0.10 mW/cm^2, a fluence of 120 J/cm^2 was achieved after 13.9 days of continuous exposure or 27.8 days of intermittent exposure with 30-minute on/off cycle times.

Results and Discussion

The 120 J/cm^2 simulated lifetime dose of UVC radiation induced a surface yellowing of the polycarbonate-based materials. The effect was pronounced in white-colored materials, with a Delta E (ΔE^*, color shift) of around 12 units. The color shift was significantly less in a medium-gray colored polycarbonate, a Delta E of 7. In black colors, the Delta E was less than 1, which is considered not perceptible. Sample chips are pictured in **Figure 1** and the full results are in **Table 2**.

The different white materials contained different amounts of white pigment, but the pigment loading appeared to have little influence on the amount of color shift seen. The color shift was also similar for different material types: polycarbonate (Makrolon®), general-purpose PC/ABS (Bayblend® T), and flame-retardant PC/ABS (Bayblend® FR).

Interestingly, the clear transparent material Makrolon® 2458 550115 showed a Delta E of only 3 in transmission, significantly less than the opaque white samples. The moderate color shift likely results from the very shallow penetration depth of UVC radiation into the polycarbonate surface (illustrated in **Figure 4**). Considering how efficiently polycarbonate absorbs UVC radiation, the extent of surface damage in all samples is likely very similar despite the different Delta E values. White pigment may simply show the yellowing, while black pigment hides it. Notably, the surface finish of all samples was unchanged after UVC exposure, with full retention of surface gloss per ASTM D523.

We found the magnitude of the color shift was essentially independent of how the UVC radiation was applied: continuously at 0.10 mW/cm^2, intermittent on/off at 0.10 mW/cm^2, or at a higher intensity of 0.35 mW/cm^2. The comparison of these dosage modes on polycarbonate of different colors is illustrated in **Figure 2**.
The results suggest that the observed color shift mainly depends on the total dose (fluence) of UVC radiation the parts see.

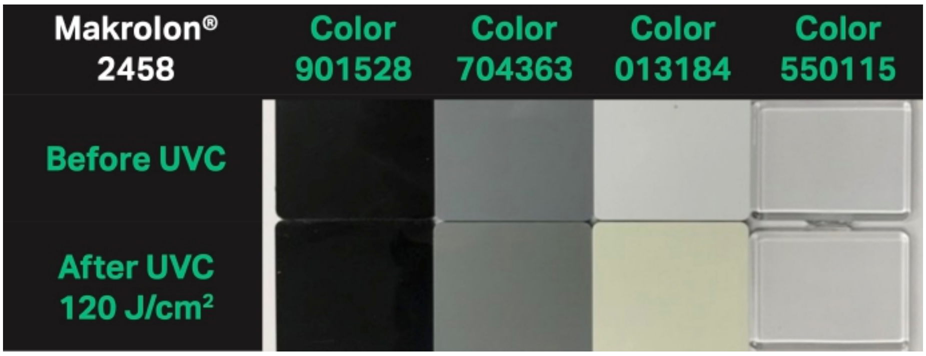

Figure 1: Appearance of materials before and after UVC exposure for four different colors of the same polycarbonate product Makrolon® 2458.

Polymer Type	Product Name	Color	ΔL* (lightness)	Δa* (redness)	Δb* (yellowness)	ΔE* (color diff.)
PC+ABS	Bayblend® FR3010 012622	White	-1.4	-3.4	13.1	**13.6**
PC+ABS	Bayblend® M301 FR 013771	White	-1.5	-3.4	13.2	**13.7**
PC+ABS	Bayblend® M850 XF 013771	White	-1.5	-3.8	14.0	**14.6**
PC+PET	Makroblend® EL700 012772	White	-1.6	-1.6	10.8	**11.1**
PC	Makrolon® RW2407 010226	White	-1.8	-4.3	16.8	**17.4**
PC	Makrolon® Rx1805 013771	White	-1.2	-3.7	12.8	**13.4**
PC	Makrolon® 2458 013184	White	-1.3	-3.9	13.8	**14.4**
PC	Makrolon® 2458 550115	Clear	-0.1	-1.1	2.8	**3.0**
PC	Makrolon® 2458 704363	Gray	-0.5	-2.3	6.4	**6.8**
PC	Makrolon® 2458 901528	Black	0.6	0.0	0.0	**0.6**
PC+ABS	Bayblend® T85 HD 901510	Black	0.6	-0.2	0.1	**0.7**
PC+ABS	Bayblend® T85 XF 901510	Black	1.0	-0.2	-0.1	**1.0**

Table 2: Color shift data for different polycarbonate and PC blends after 120 J/cm^2 exposure (0.10 W/m^2).

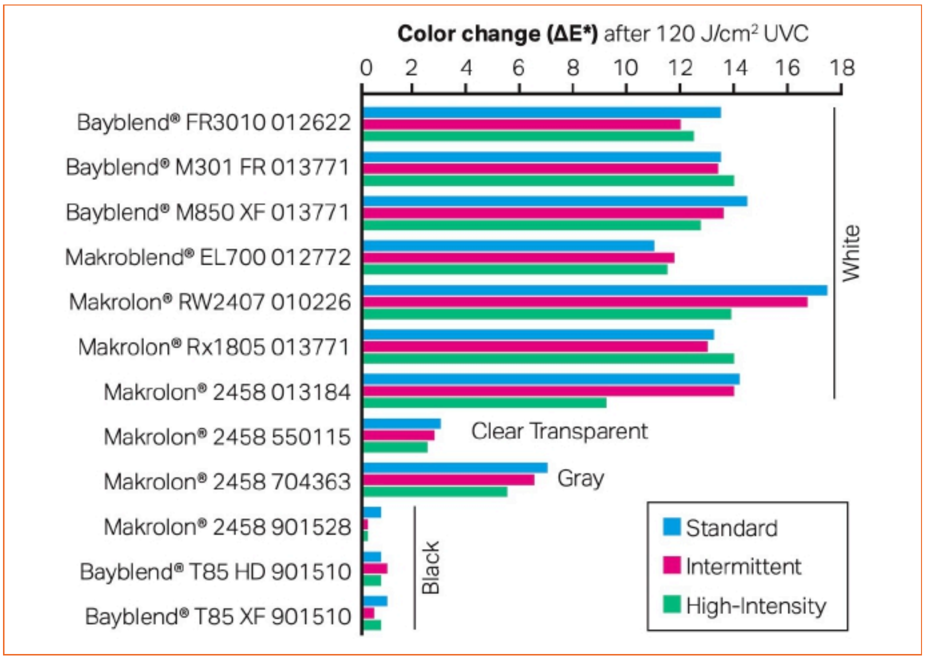

Figure 2: Post-UVC color shift after 120 J/cm^2.

This may facilitate comparisons between UVC exposure experiments done at different irradiances.

Kinetics of the color shift versus UVC exposure were measured using a handheld color meter; see **Figure 3**. A saturation response was seen for all samples: yellowing was much more rapid at first, with roughly half of the eventual color shift seen at 120 J/cm² coming within the first 30 J/cm² of exposure. There was no significant difference in yellowing whether the samples were irradiated continuously or intermittently. The rapid saturation behavior was also seen for polycarbonate elsewhere1; it implies that additional UVC radiation beyond 120 J/cm² may result in only slightly more yellowing. Aesthetics are important for many products that are repeatedly disinfected, but often a more pertinent question is whether a material's physical properties are retained after disinfection.

We chose one polycarbonate and one PC/ABS blend and compared their tensile properties, impact resistance, and heat resistance before and after UVC exposure. All properties were fully retained within experimental error for all three exposure modes: continuous, intermittent, and high intensity, as shown in **Table 3**.

It's interesting to note that no property changes were detected despite the distinctive yellowing seen in the white samples. While these were bulk properties measurements, tensile properties and impact properties can be sensitive to surface damage, since a damaged surface can induce a brittle failure mode [4]. Also, the Vicat softening temperature measurement uses a small needle to probe the material, so it can be sensitive to surface degradation as well. The fact that these properties were retained is an encouraging indication that polycarbonates are mechanically suitable for repeat UVC disinfection.

The lack of physical properties or surface change after UVC exposure contrasts the experience of outdoor weathering of polycarbonates. UVA and UVB are known to result in surface degradation and reduced bulk properties given sufficient exposure. A likely contributing factor is the shallow penetration depth of UVC, which results from the very high absorption of polycarbonate in the UVC wavelength range [5].

A cross-sectional light microscopy image of a microtomed UVC-exposed sample showed visible yellowing only near the sample surface, depicted in **Figure 4**. The rapidly yellowing surface layer may act as a protective barrier shielding the bulk material underneath from UVC exposure.

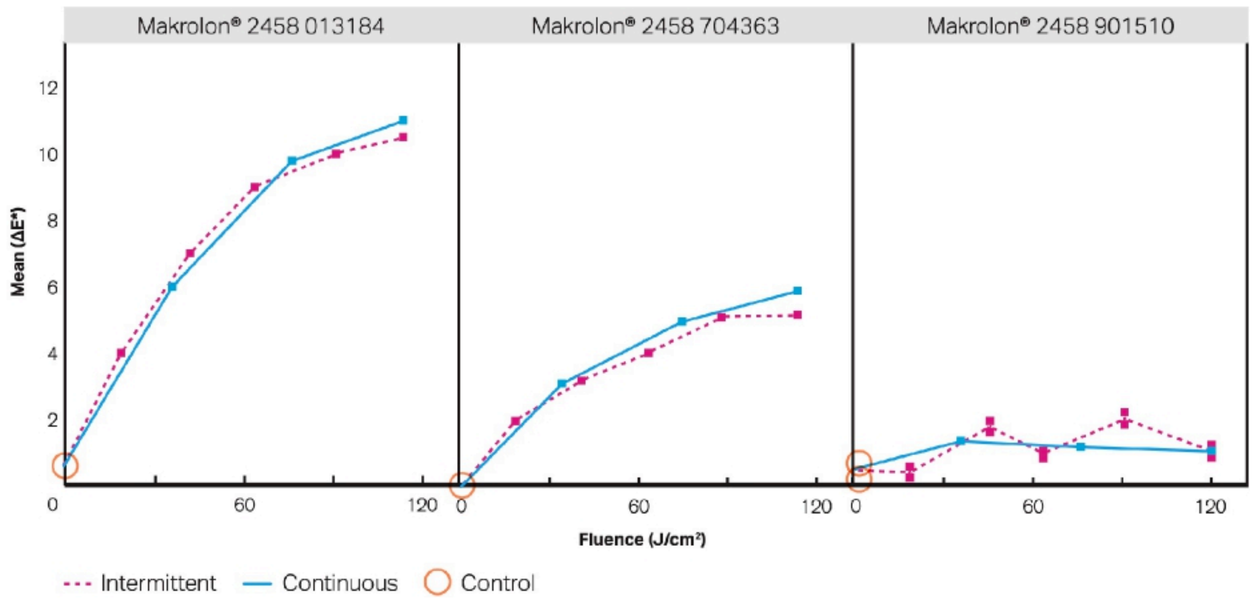

Figure 3: Color shift vs. fluence (or dosage) for white, gray, and black colors of Makrolon® 2458.

Bayblend® T85 XF 901510 (black PC/ABS)			**No UVC** Control	Continuous	**Post-UVC** Intermittent	High-Intensity
Izod notched impact strength, 23°C (4mm)	ISO 180/A	kJ/m²	45	45	47	46
Tensile modulus	ISO 527-1, -2	MPa	2390	2390	2400	2370
Tensile yield stress	ISO 527-1, -2	MPa	53.7	53.6	53.7	53.6
Vicat softening temp. (50 N, 120°C/h)	ISO 306	°C	127	127	127	127

Makrolon® 2458 550115 (clear PC)			**No UVC** Control	Continuous	**Post-UVC** Intermittent	High-Intensity
Izod notched impact strength, 23°C (3mm)	ISO 7391 / ISO 180/A	kJ/m²	56	60	62	56
Tensile modulus	ISO 527-1, -2	MPa	2460	2460	2440	2460
Tensile yield stress	ISO 527-1, -2	MPa	62.8	62.9	62.9	62.9
Vicat softening temp. (50 N, 120°C/h)	ISO 306	°C	144	144	144	144

Table 3: Physical properties retention after 120 J/cm² UVC exposure via three different exposure modes.

Conclusions

Polycarbonates and PC blends appear to be well suited to applications in which they are repeatedly disinfected by UVC. Although lighter colors yellow when exposed to a simulated lifetime dose of UVC radiation, transparent and darker colors show a milder color shift, and black colors show no perceptible change. The high absorption of UVC radiation by polycarbonate appears to result in a shallow penetration depth, with the outer surface of the plastic part protecting the bulk from damage. While the cumulative dose of 120 J/cm^2 studied here approximates thousands of disinfection cycles, even higher doses may be of interest for applications in which polycarbonates are used in the housings of UVC lamps or for equipment which is kept very close to UVC sources. The rapid saturation kinetics of yellowing implies that even much higher doses may result in only slightly more yellowing. ■

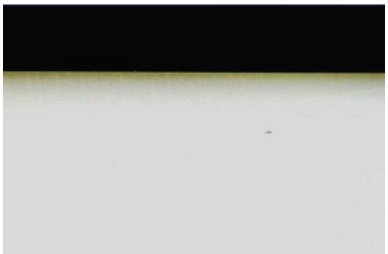

Figure 4: Cross-sectional light microscopy (160×) view of the surface of a white part; the sample is at the bottom and the background appears black. The yellowing is seen to penetrate only a small distance from the surface, with most of the color shift appearing within 15 microns of the surface, and nearly all of it within 50 microns. Additionally, the surface is smooth and unperturbed by UVC exposure.

Acknowledgments
The authors thank Karen Stewart for microtoming and optical microscopy and Rudy Gorny, Paul Platte, and Nick Sunderland for helpful discussions.

References

[1] West MD, Ruys AJ, Bosi SG. "The Effect of the Ultraviolet Radiation. Environment of LEO upon Polycarbonate Materials" 43rd AIAA Aerospace Sciences Meeting and Exhibit 2005-662 (2005)
[2] Honeywell "Effect of UVC Exposure on Non-Metallic Materials in HVAC. Systems" https://digitalassets.resideo.com/damroot/Original/10004/50-8788.pdf (2000) retrieved on 14-Dec 2020.
[3] Malayeri AH, Mohseni M, Cairns B, Bolton JR, et al. "Fluence (UV Dose) Required to Achieve Incremental Log Inactivation of Bacteria, Protozoa, Viruses, and Algae" IUVA.org; https://www.iuvanews.com/stories/pdf/archives/180301_UVSensitivityReview_full.pdf (2016) retrieved on 14-Dec 2020.
[4] Sherman ES, Ram A, Kenig S, "Tensile failure of weathered polycarbonate" Polym. Eng. Sci. 22, 457-465 (1982)
[5] Andrady AL, Searle ND, Crewdson LFE, "Wavelength sensitivity of unstabilized and UV-stabilized polycarbonate to solar simulated radiation" Polym. Deg. Stab. 35 235-247 (1992)

Routes in the Development of Simulation Models for Light Scattering Thermoplastics

An option for significantly reducing time and the number of development cycles for acrylic light scattering optical elements is demonstrated. The theoretical Mie approach for simulation of light scattering elements requires detailed knowledge of both optical data of the matrix material as well as optical data of the scattering particles including the concentration thereof. However, extensive data are barely accessible for end users, often requiring additional, expensive in-depth measurements, and frequently resulting in a mismatch of simulation to the optical performance of the manufactured part. On the contrary, an experimental approach requires optical knowledge of the polymer matrix only and aims for isolating single scattering events by aid of dilution of the scattering particle within the matrix. Mathematical fits of the phase functions with Henyey–Greenstein and Gegenbauer models are performed, demonstrating that the experimental approach correlates very well with actual measurements.

Introduction

The release of white LEDs to the market opened a new chapter in the lighting industry. LED light sources offer huge potential in terms of energy efficiency, reduced installation space and lifetime. At the same time, new challenges arise, e.g. changes in thermal management and the need for optical management of light distribution: the LED as point light source with high luminous flux requires light diffusors in many general, specialty and automotive lighting applications to generate a homogeneous light distribution, to avoid hot spots and glaring, and to fulfill the requirements of norms and standards.

Conventional light sources typically relied on non-sophisticated plastic diffusors based on inorganic scattering materials that are added to a polymeric matrix. However, the high portion of back-scattered light gave rise to tailored diffusor systems for LED lighting applications, which are characterized by strong forward scattering properties.

The interaction of LED light with the scattering particles embedded in the polymeric matrix defines the final diffusion properties of the plastic material. Stronger or weaker diffusors are required depending on the lighting and luminaire design, which requires changes to the composition of the light scattering, diffuse plastic material. The main parameters for the definition of this characteristic are the concentration, the composition and the size of the light scattering particles. These main parameters determine the used scattering regime (Rayleigh-, Mie- or geometrical scattering) as well as single or multiple scattering properties. Moreover, scattering properties are dependent on the wavelength. Therefore, a good knowledge of the physical principles is required to determine the performance of a final component.
In the recent past, the optical design of a light-scattering component was often based on an empirical approach including several development cycles and handcrafted prototypes. Currently, several industries are calling for much shorter development times, which requires precise optical simulation which can be used in serial processes directly. Röhm GmbH is supporting this industry need and has developed precise simulation models for its light scattering acrylic molding compounds. The intensity as well as the spectral distribution of a component can be simulated by using these models. The following report summarizes the routes and results for the determination of material models for acrylic light scattering materials.

Theoretical Background

Interaction of light with matter results in absorption, reflection, diffraction, refraction and diffusion, respectively. For the development of simulation models, these main physical principles need to be considered and translated into material development. In short, Huygens-Fresnel law, Snell's law and Lambert-Beer-Bouguer law describe light diffraction, refraction and absorption.

Light scattering in diffuse thermoplastics is an elastic scattering and occurs when radiation is forced to deviate from its straight trajectory by aid of selectively placed scattering particles. The Lorenz-Mie solution to Maxwell's equations describes the scattering of an electromagnetic plane wave by spherical particles of any size. Different particle size regimes allow simplification of the complex Mie solution: Rayleigh scattering and geometrical optics are two relevant theories for light scattering at different particle sizes. The Rayleigh model is a common simplification for cases in which the diameter of the scattering particle is smaller than the wavelength of incoming light ($d <$ 0.1–0.2 λ). Particles much larger than the wavelength of the incoming light are best described with the geometrical optics model ($d > 3\ \lambda$). There are no hard limits for the different scattering regimes [1]. **Figure 1** describes the different characteristics of the scattering regimes, from a spherical phase function at Rayleigh regime to a forward scattering at geometrical optics [2].

The phase function for a scattering particle can be determined exactly with the Mie theory [3] which requires particle size, wavelength, refractive index of the scattering particle and refractive index of the matrix material. However, the Mie solution to Maxwell's equations is still complex. Therefore, phenomenological phase functions have been established for the multiple use cases e.g. the light scattering thermoplastics. Most common are the functions of Henyey–Greenstein [4] and Gegenbauer [5].

Henyey and Greenstein introduced a model in which the phase function of a scattering particle is determined by varying the anisotropy factor g_{HG} (**Equation (1)**). The parameter g_{HG} is within the limits $-1 < g_{HG} < 1$ and describes the scattering behavior of a particle (-1 – backward, 0 – isotropic, 1 – forward scattering). That indicates that this model works with a fixed slope of the phase function.

$$p_{HG}(\theta, g_{HG}) = \frac{1}{4\pi}\frac{1-g_{HG}^2}{(1+g_{HG}^2-2g_{HG}\cos\theta)^{\frac{3}{2}}}$$

Equation (1): Henyey–Greenstein phase function. θ being the scattering angle.

The Gegenbauer model overcomes the limitations of the Henyey–Greenstein phase function [6] by utilizing two parameters (g_{GGB} and α) for the modulation of the phase function (**Equation (2)**). It better describes scattering behavior by enabling more accurate fit of curves with steep slopes or pronounced peaks. The first anisotropy factor is also within the limits $-1 < g_{GGB} < 1$, the second factor α_{GGB} has the lower limit -0.5. The Gegenbauer model with $\alpha = 0.5$ corresponds to the Henyey–Greenstein model.

$$p_{GGB}(\theta, \alpha_{GGB}, g_{GGB}) = \frac{\alpha_{GGB}\cdot g_{GGB}}{\pi} \frac{(1-g_{GGB}^2)^{2\alpha_{GGB}}}{[(1+g_{GGB})^{2\alpha_{GGB}}-(1-g_{GGB})^{2\alpha_{GGB}}]} \frac{1}{(1+g_{GGB}^2-2g_{GGB}\cos\theta)^{(1+\alpha_{GGB})}}$$

Equation (2): Gegenbauer phase function. θ being the scattering angle.

Simulation Models

Simulation models for thermoplastic scattering materials offer the option to feed simulation software with parameters and to implement materials with pre-defined parameters into a software, respectively. Generally, such parameters can be obtained either through scientific or through experimental approaches. Both require knowledge of the optical properties – absorption and refractive index – of the matrix material in which the scattering particles are embedded. These properties can be determined by aid of standard optical characterizations. Differences arise in the analysis of the scattering particles:

The scientific approach requires additional characterization of the scattering particle itself (size, shape, refractive index and its wavelength dependency). Moreover, the exact concentration in the polymer matrix must be known. Commonly, details on scattering particles and their concentration in a matrix are not disclosed by material manufacturers. Another disadvantage of the scientific approach is that only ideal parameters for scattering particles – exact same geometry, size and composition – can be entered into a simulation software. This commonly leads to deviations when compared with real-life specimens, because the impact of e.g. the material processing or particle agglomeration cannot be considered.

The experimental approach considers the scattering particles in a real-life product. Single scattering events can be accessed by means of dilution [7]. To this end, the concentration of scattering particles in a real-life product is lowered by aid of dilution with the matrix material.

The K-factor, defined as the quotient of mean free path length (MFP) and thickness of the sample, supports the estimation whether the single scattering regime is reached. By lowering the concentration of scattering particles, the MFP increases, as does the K-factor. Typical K factors for single scattering should be in the order of ≥10, with smaller values indicating that multiple scattering events are detected and not the phase function of a single particle. Naturally, the experimental approach accounts e.g. for influences from material processing and scattering particle agglomeration.

Due to the required material input, the Mie theory is suitable only for the scientific approach, while the Henyey–Greenstein and Gegenbauer models can be used for the experimental approach.

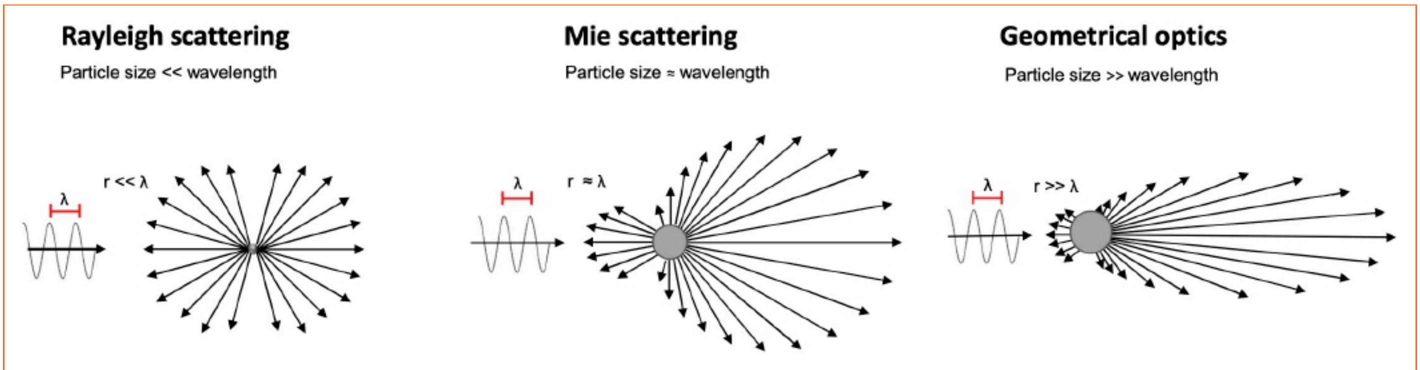

Figure 1: Different scattering regimes and their scattering characteristics.

Experimental

Sample 1: PLEXIGLAS® 8N LED 0V206; scattering particles follow the Mie-regime
Sample 2: PLEXIGLAS® Satinice df23 8N; scattering particles follow geometrical optics.

Dilution series of Sample 1 and Sample 2 were prepared by dry-blending PLEXIGLAS® 8N LED 0V206 respectively PLEXIGLAS® Satinice df23 8N with defined amounts of PLEXIGLAS® 8N clear, followed by homogenization at 250 °C in a single screw extruder (Stork 30). The obtained cylindrical resin was injection-molded to high optical quality specimen 40 x 40 x 1,2,3,4 mm^3 (Arburg Allrounder 320C Golden Edition; hot runner system with needle valve nozzle).

A g0p inplane Goniometer (Opsira) was used for the characterization of standard products and dilution series. Wavelength sensitive irradiance was recorded in a typical range of 380–780 nm with a maximum resolution of 1 nm. The influence of the light source is eliminated by subtracting results of samples without scattering particles (PLEXIGLAS® 8N clear), resulting in a loss of data points at very small scattering angles. To reduce further the number of datapoints, wavelength packages are clustered. Henyey–Greenstein (g_{HG}) and Gegenbauer (g_{GGB} and α_{GGB}) were fitted to measurement data by considering refraction according to Snell's law. All simulations were performed with LucidShape, version 2019, from Synopsys.

Results and Discussion

Scientific Approach

LucidShape allows the simulation according to the Mie-theory, when material data from both the matrix material and the scattering particles are available. Only ideal parameters are entered, which does not account for the impact of e.g. processing and sample preparation. Moreover, the wavelength-dependency of the refractive index of the scattering particle must be known in order to obtain exact simulations at different wavelengths.

Figure 2 shows Mie-simulation data as well as measured data for Sample 1 and Sample 2 at different wavelengths. Both samples show significant deviations between simulation and real-life scattering behavior. The Mie-simulation data show high deviations for thin-walled specimens in particular. Remarkable for Sample 1 is the high portion of unscattered light (±0°) in the simulation.

Increasing the sample thickness results in a better match between actual behavior and Mie-simulation. This is especially true for Sample 1, while Sample 2 (geometrical optics) still shows differences which are unacceptable for industry simulations (**Figure 3**).

The above examples show that simulations according to the Mie-theory can deliver good results if the parameters used for the particles are very precise and independent of the wavelength. However, a mismatch of input and real-life parameters of the scattering particles leads to inaccurate results. In particular, the wavelength-dependency of the refractive index of the scattering particle could not be considered in this example.

Experimental Approach Mie Regime

The experimental approach tries to overcome the practical difficulties of the scientific approach by determining the phase distribution function of a single scattering event in a diluted real-life product. Sample 1 with a Mie-scattering particle was processed accordingly and shows the feasibility of this process. The wavelengths in **Figure 4**, left are not separated, which indicates that multi scattering is the dominating process. On further reducing the concentration (**Figure 4**, right) the wavelengths are clearly separated and a K value of ≈ 10 can

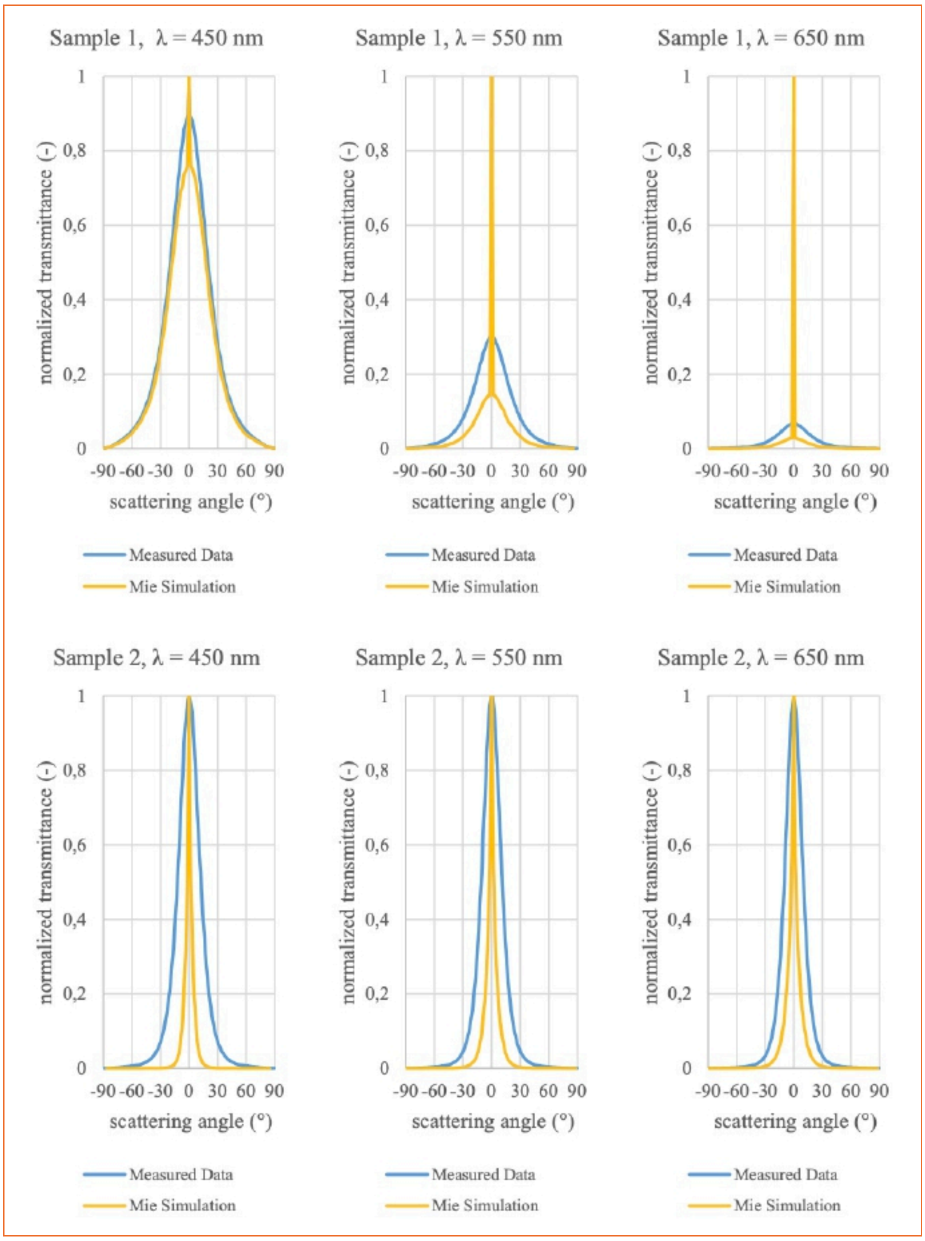

Figure 2: Comparison of Mie-simulation with measured data for Sample 1 and Sample 2 at three selected wavelengths and 1 mm thickness.

be estimated, i.e. single scattering is the dominant process, the regime for simulations is reached.

Both the Henyey–Greenstein and the Gegenbauer phase functions are fitted with the measurement data of the single scattering event, resulting in the parameters g_{HG}, g_{GGB} and α_{GGB}. These are only dependent on the wavelength and do not change with varying scattering particle concentration. The results are summarized in **Figure 5**. As expected, the Gegenbauer fit reproduces the actual measurement very well while the Henyey–Greenstein model with only one parameter shows weaknesses.

The concentration of the scattering particles within the polymer matrix is expressed by the mean free path and is dependent on the wavelength. The MFP can be calculated with the Mie-theory and measured under certain circumstances [7].

The determined parameters for Sample 1 are summarized in **Table 1**, with the resulting simulations in **Figure 6**. The results clearly show the advantage of the Gegenbauer fit. The scattered part of the light is calculated sufficiently for all wavelengths, as is the unscattered light portion. Henyey–Greenstein fit with only one parameter does not sufficiently reproduce the actual scattering behavior of scattered and unscattered light. Thicker or higher scattering samples can be simulated accordingly. Because of more scattering events, the peak for unscattered light is no longer visible and again, the Gegenbauer function shows a more accurate result which is in accordance with literature findings [5].

Experimental Approach Geometrical Optics

The Henyey–Greenstein phase function was shown to not properly simulate the behavior of scattering particles for Sample 1. Therefore, only the Gegenbauer parameters are determined for Sample 2 with scattering particles $d > 3\,\lambda$, i.e. geometrical optics. The parameters shown in **Table 2** eliminate influences from sample preparation and processing and overall lead to good simulation results even for thin walled parts (**Figure 7**).

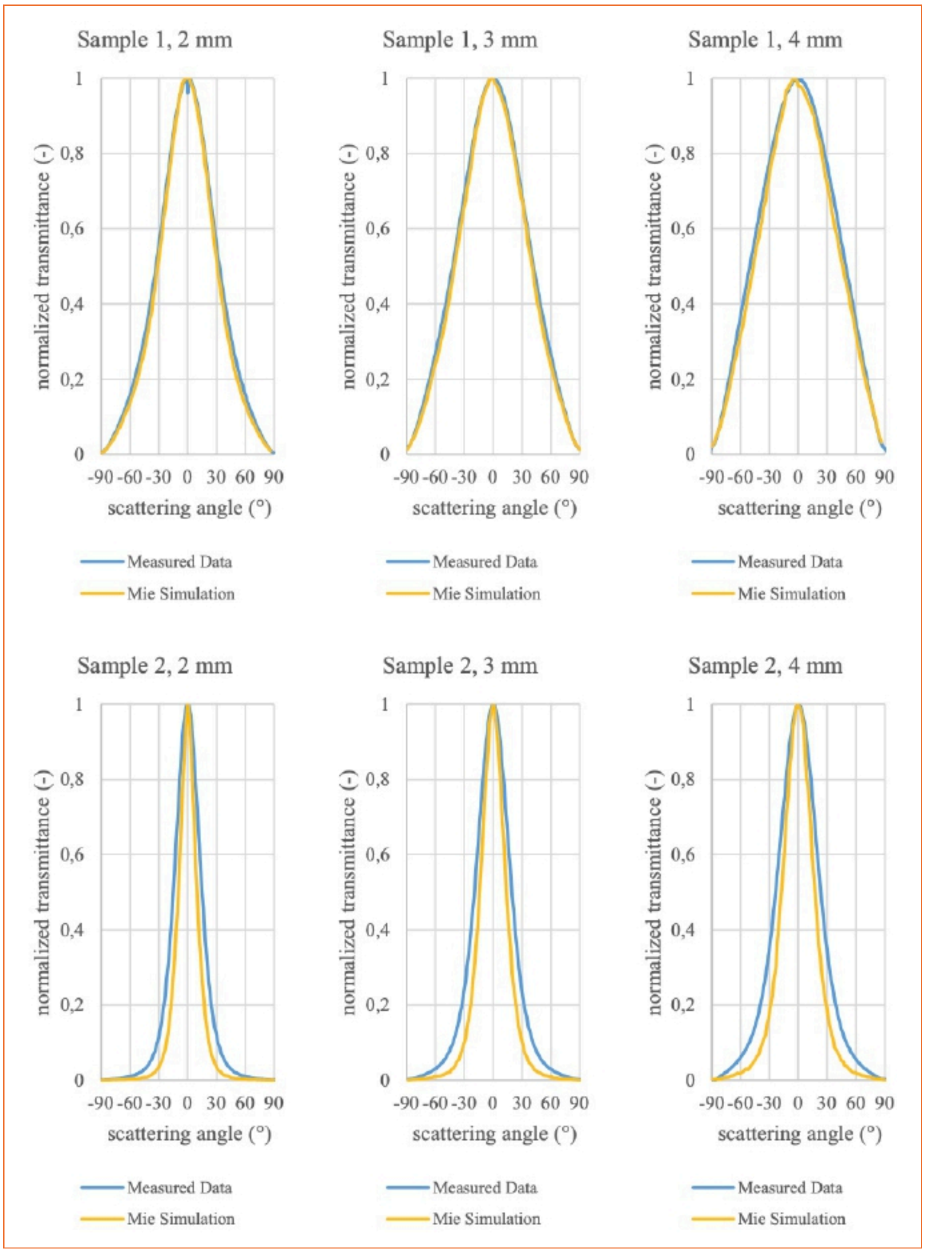

Figure 3: Comparison of Mie-simulation with measured data for Sample 1 and Sample 2 at three selected thicknesses and 550 nm.

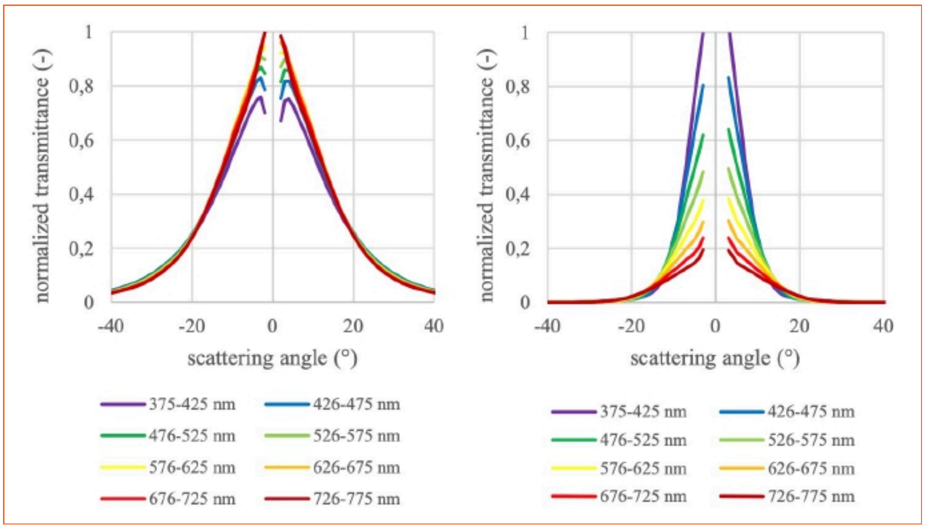

Figure 4: Dilution series of Sample 1. Left: multiple scattering processes dominate, dilution insufficient; right: dilution sufficient.

Conclusion

Theoretical approaches such as the classical Mie theory have been commonly used to simulate thermoplastic volume scattering materials for LED lighting applications. For end-users, this practice frequently fails because in-depth material data are not provided or not known by the vendors. Materials investigated in this work are well known to the authors and best characterized. Still, this approach does not result in satisfying simulation data, which is mainly reasoned with a material history, i.e. influences from processing, which cannot be factored in with ideal data sets.

"Our customers value accurate simulation data because the design-to-tool time is significantly reduced, and the development process becomes less expensive."

DR. RENÉ KOGLER

On the contrary, an experimental approach starts with real-life samples, and single scattering events can be accessed by aid of diluting the sample with the matrix polymer until the regime of single scattering events is reached. By doing so, a material history caused by processing as well as non-ideal behavior of scattering particles, e.g. agglomeration, is already accounted for. The feasibility of this process is demonstrated and subsequent simulations with phase functions utilizing one (Henyey–Greenstein) or two (Gegenbauer) parameters show that a good correlation to measurement data exists. The two-parameter Gegenbauer model is found to be superior to the one-parameter Henyey–Greenstein fit, especially for thin-walled specimens.

In technical data sheets for light scattering plastics, often the half value angle or the scattering power are displayed. Both are single point data aiming to describe scattering distribution function. Half value angle is determined as the angle at which the light intensity is half of its intensity at the 0° measurement. Scattering power is using the light intensity at 3 predefined angles [8]. **Table 3** displays the values for half value angles as well as scattering power from measured and simulated graphs. The Gegenbauer-model proves its accurate fit to real life data. ■

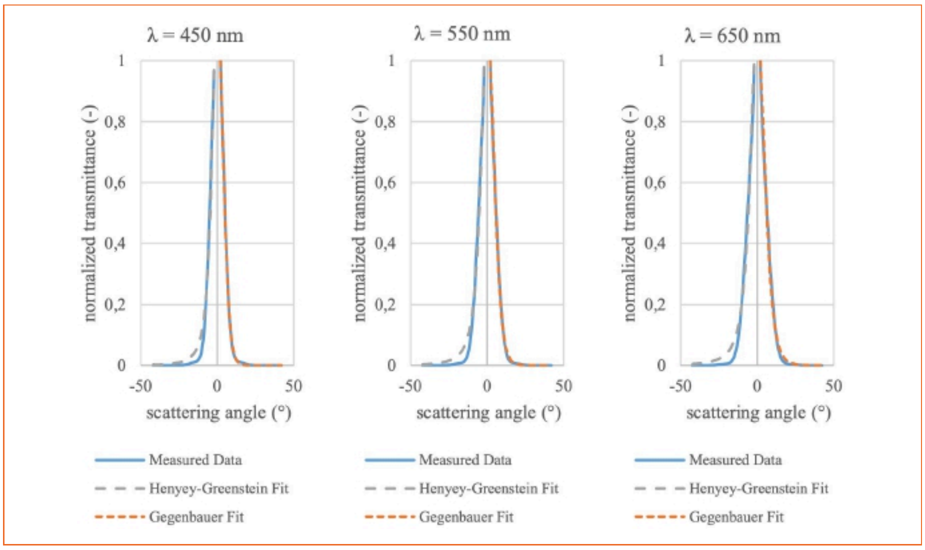

Figure 5: Henyey-Greenstein and Gegenbauer fit for Sample 1 at different wavelengths and 1 mm thickness.

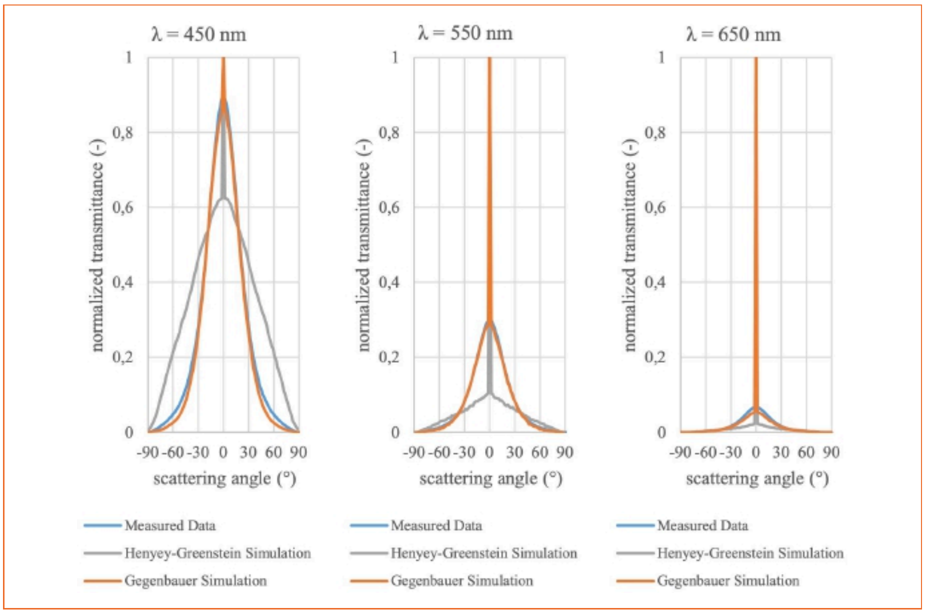

Figure 6: Comparison of measurement and simulations of Sample 1 at three selected wavelengths and 1 mm thickness.

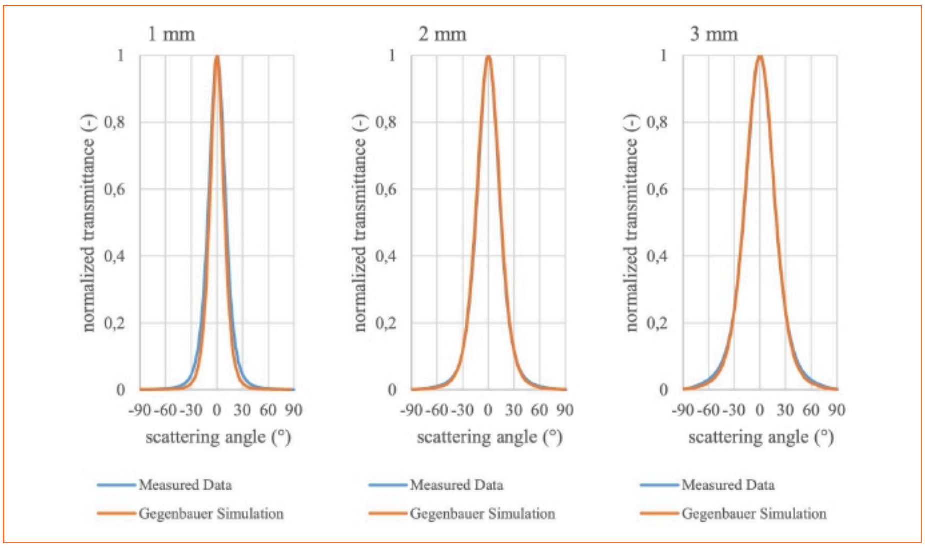

Figure 7: Comparison of measurement and simulation of Sample 2 at three selected thicknesses and one wavelength.

Wavelength (nm)	MFP (mm)	g_{HG}	g_{GGB}	α_{GGB}
450	0.095	0.915	6.837	0.771
550	0.133	0.899	4.348	0.780
650	0.180	0.887	2.497	0.804

Table 1: Simulation parameters for Sample 1.

Wavelength (nm)	MFP (mm)	g_{GGB}	α_{GGB}
450	0.065	1.155	0.972
550	0.06	1.135	0.977
650	0.06	1.116	0.980

Table 2: Simulation parameters for Sample 2.

			Half Angle				Scattering Power			
Material	Thickness	λ (nm)	Measured Value (°)	Mie (°)	GGB (°)	HG (°)	Measured Value	Mie	GGB	HG
Sample 1	1 mm	450	20	17	19	23.4	0.304	0.320	0.304	0.538
		550	0.7	1	1.3	1	0.28	0.251	0.280	0.464
		650	0.5	0.9	0.9	0.9	0.257	0.217	0.282	0.364
	2 mm	550	33	30.6	32.4	–	0.43	0.417	0.429	–
	3 mm	550	42	40	41.4	57	0.505	0.498	0.494	0.603
	4 mm	550	50	46	46.8	–	0.557	0.539	0.546	–
Sample 2	1 mm	450	13	1.8	10.2	–	0.129	0.010	0.084	–
		550	11	2.2	9	–	0.098	0.031	0.063	–
		650	10	2.5	8.2	–	0.08	0.045	0.044	–
	2 mm	550	15	10.8	15.4	–	0.177	0.091	0.189	–
	3 mm	550	20	13.8	19.8	–	0.263	0.162	0.268	–
	4 mm	550	24	17.3	23.4	–	0.325	0.229	0.328	–

Table 3: Half angle and scattering power for Sample 1 and Sample 2 at different wavelengths and thicknesses.

References

[1] M. Frühwein, Spektrale goniometrische Vermessung von volumenstreuenden Formmassen, Master Thesis, University of Applied Sciences Darmstadt, 2018

[2] J. Rohmann, Laboruntersuchungen an einzelnen elektrodynamisch levitierten Modell-Seesalzaerosolen unter Verwendung der Mie-Streuung, PhD Thesis, Osnabrück University, 2003

[3] C.F. Bohren and D.R. Huffman, Absorption and Scattering of Light by Small Particles, John Wiley & Sons, Inc., New York (1983).

[4] L. G. Henyey and J. L. Greenstein, Diffuse Radiation in the Galaxy, Astrophysical Journal, Vol. 93, p. 70-83 (1941)

[5] L.O. Reynolds and N. J. McCormick, Approximate two-parameter phase function for light scattering, Journal of the Optical Society of America, Vol. 70, p. 1206–1212 (1980)

[6] K.W. Calabro and W. Cassarly, Modeling scattering in turbid media using the Gegenbauer phase function, Proceedings of the SPIE, Vol. 9333, 93330F (2015)

[7] Draft directive VDI/VDE 5596, Optical design for manufacturing - Illumination optics, non-imaging and freeform optics: Optical design process, Part 3

[8] DIN 5036, Strahlungsphysikalische und lichttechnische Eigenschaften von Materialien; Meßverfahren für lichttechnische und spektrale strahlungsphysikalische Kennzahlen, 1979-11

About Röhm

With 3,500 employees and 15 production sites worldwide, Röhm is one of the leading manufacturers in the methacrylate business. The medium-sized company with branches in Germany, China, the USA, Russia, and South Africa has more than 80 years of experience in methacrylate chemistry and a strong technology platform. Our best-known brands include PLEXIGLAS®, ACRYLITE®, MERACRYL™ , DEGALAN®, DEGAROUTE® and CYROLITE®.

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Parametric Design Optimization of an LED System Using Engineering Simulation in the Cloud

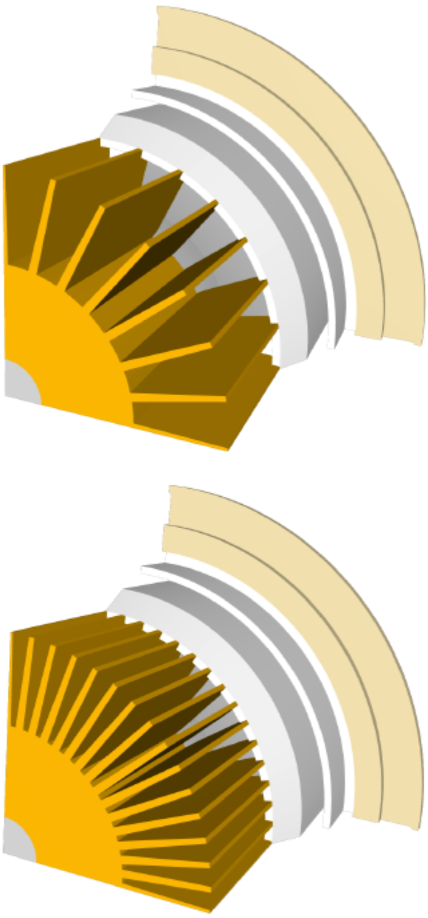

Figure 1: CAD model of a 28 fin LED (top) and 60 fins LED (bottom) for CFD simulation.

Computational Fluid Dynamics (CFD) is a type of engineering simulation that models the behavior of fluids (liquids and gases). CFD is used in most engineering design types to evaluate the impact of heat transfer, fluid and material properties, and the product's operating environment or system being developed. This innovative computation method proves to be especially useful for the thermal management of electronics products such as LEDs, phones, laptops, healthcare devices, and microprocessors. In essence, a digital duplication of an object, such as an LED, is created and then mathematically simulated using parameters to assess real-world performance based on a set of assumptions.

A typical workflow involves importing 3D cad models (**Figure 1**) into the CFD software, applying boundary conditions (e.g., the material properties of an LED, the lighting power density, ambient temperature, etc.), simulating and analyzing the results (post-processing). Simulating in the cloud (CFD software accessible via a web-browser) also means that cloud computing power is harnessed to deliver fast results in a collaboration-enabled environment. Designers, engineers, and manufacturers can work on the same project remotely.

Cloud Simulation

CFD in the cloud gives engineers and designers alike the ability to access simulation from anywhere, through their preferred web browser. The native application is hosted and run entirely in the cloud, making it accessible and secure, eliminating the need for in-house storage solutions. Simulating in the cloud boasts scalability through on-demand computing power, without expensive and local hardware. This means an engineer designing an LED can set up and run dozens of simulations simultaneously for each model variation, various operating points, and working conditions for the same LED design.

Case Study

CFD is used to optimize the design of an LED SMD. When designing an LED, the thermal management of the product is critically important. Sub-optimal heat dissipation can cause component degradation leading to reduced life and, ultimately, failure. In this example, multiple types and numbers of LED heat sink fins were modeled to evaluate the range of options that would lead to optimal performance. Two design variations of an SMD rated at 33 W and a warm white color temperature of 3000 K are presented. An LED with 60 heat exchanger fins and one with only 28. The latter performs better. Although this might seem counter-intuitive, to begin with, the CFD analysis shows better penetration of air between the cooling fins, even though the amount of heat exchanger material is less. The design with 28 fins is also cheaper to manufacture, thus validating the exercise and providing a clear return on investment for such a study. **Figure** 2 summarizes the results. The design with 28 fins provides 6□ more cooling (7%) compared to having 60 fins.

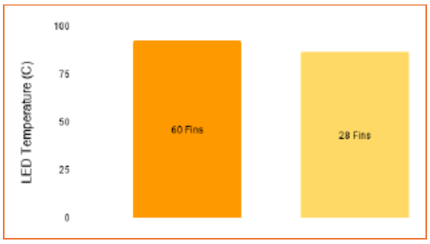

Figure 2: LED temperatures for 60 and 28 cooling fins for the LED system.

Figure 3 illustrates the heatsink design's effectiveness by clearly showing a reading of the simulated LED surface temperature. The heatsink design with 28 heatsink fins transfers more heat away from the LED. The LED's surface temperature is 6 °C cooler and would therefore have a longer expected operating lifetime.

Benefits of Using CFD

The simulation used a conjugate heat transfer analysis to simulate the heat transfer between the components, solids, and fluids. This thermal analysis type ensures that as much physics as possible is being captured, giving data-driven results to lead to faster design decisions. In this case, the solid parts are the SMD LED-heatsink and the lighting housing. The solid-fluid interaction is between the heatsink and lighting housing to the surrounding air. Heat is exchanged in this simulation at the interfaces, where solid-solid and solid-fluid make contact and, transported via conduction within the solid materials. Additionally, energy is transferred via convection within the fluid (air).

Figure 4 shows a heat sink and air temperature plot for the LED with 60 fins (left) and 28 fins (right). The images show a cutting plane that intersects the heatsink. The airflow around the heatsink is represented by velocity vector arrows that are projected onto the cutting plane. The magnitude of the vector is an indication of the relative flow velocity. Warmer temperatures are indicated in red.

An interesting result of the analysis was that the design with 60 fins did not transfer the heat from the heatsink fins to the surrounding air as effectively as the design with 28 heatsink fins. Hand calculations and designer intuition would suggest that a 60 fin heatsink, with a greater surface area for convective heat transfer, would be superior to a 28 fin heatsink, with a much lower surface area available for dissipating heat.

The CFD analysis, however, shows that the heatsink with 60 fins does not allow the air to penetrate and flow sufficiently into the gaps between the fins. It effectively limits the heatsink fins' functional surface area for convective heat transfer to the surrounding air. In contrast, the design with 28 heatsink fins has a more open design that allows a higher airflow around the heatsink. This design utilizes the entire depth of the heatsink fins for effective convective heat transfer.

Summary

CFD simulation in the cloud is used to model and simulate multiple design configurations of an LED. Parallel computing capabilities mean engineers can evaluate dozens of design scenarios simultaneously on a web browser, faster than ever before. CFD can enable designers and engineers to analyze external influences and the physics inside an electronic device, allowing them to quickly converge on a final design by simulating its LED performance, saving time and cost of R&D by order of magnitude. ■

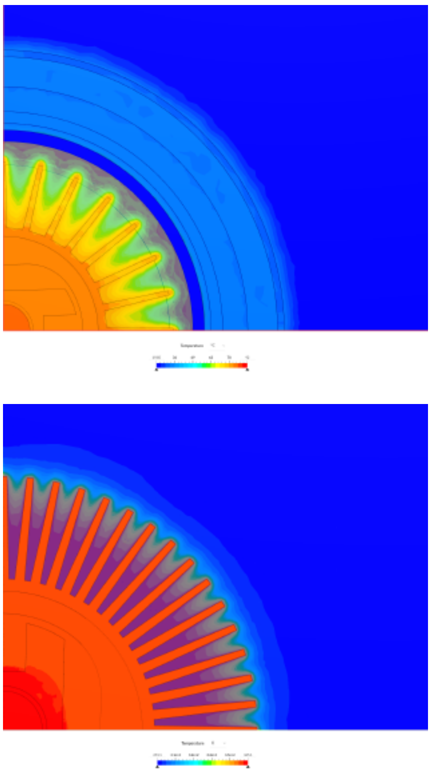

Figure 3: Temperature of two design variations of an LED. Top, with 28 fins and a peak temperature of 86.65 □ and bottom, with 60 fins and a peak temperature of 92.55 °C. Warmer temperatures are indicated in red.

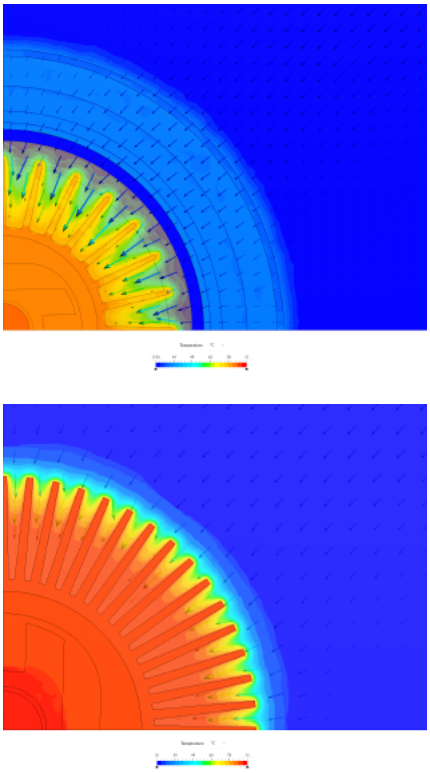

Figure 4: Temperature of two design variations of an LED. Top, with 28 fins (cooler) and bottom, with 60 fins (warmer).

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Spectroscopy with Broadband visible-NIR and Multi-chip Narrowband SWIR LEDs

Historically, broadband illumination light sources were the de facto solution for many applications. From tungsten-halogen infrared (IR) to ultraviolet (UV) xenon arc lamps, broadband was simply the only solution on offer. All of that changed with the emergence of solid state lighting (SSL) technology. SSL allowed device manufacturers to embrace pinpoint accuracy in distribution and intensity, precisely controlled spectral emissions, and never before seen efficiency and heat dissipation abilities.

The arrival of light-emitting diode (LED) and laser diode (LD) SSL technologies did not spell the end of broadband illumination. Instead, the door to new advancements could be opened. Already producing a wide range of narrowband single and multi-chip LEDs, from 365–1750 nm short-wavelength infrared (SWIR), Ushio doubled down on its broadband engineering efforts. The challenge to find a single solution that could cover the entire spectrum between visible and near infrared (NIR) culminated in the development of the most powerful broadband LED series in the world - Spectro.

Broadband LEDs

Broadband LED technology relies on an indium gallium nitride (InGaN) chip mounted in an SMBB package. Ideal for spectroscopy and spectral imaging applications, broadband LEDs emit wavelengths across the visible and NIR spectrum, from violet 400–1000 nm. This is important as the cost-effective CMOS (complementary metal-oxide-semiconductor) photodetector chips are particularly sensitive to this wavelength range. SMBB type packages bring excellent heat dissipation qualities and a choice of lens options. Meanwhile, the InGaN chip provides high optical output power, up to 180 mW, for an LED emitting light in the 500–1000 nm range.

- Hyperspectral wavelength emission: 400–1000 nm
- Stable emission spectrum: by using a complex phosphor, which has an emission spectrum that remains stable against temperature and forward current, the desired 500–1000 nm broadband emission is achieved
- Compact SMBB package: technology is renowned for its easy installation, design integration, small footprint
- High standard of heat dissipation
- Long life: broadband LEDs last far longer than conventional halogen alternatives
- Lens selection: Flat and -02 type lenses are compatible, which allows easy viewing angle manipulation for the desired illumination
- Highest optical output power for a broadband LED: a total radiation flux of 180 mW in the CMOS-sensitive visible to infrared wavelength range, from 500–1000 nm

Importance of Broadband LEDs

Many organic materials absorb certain wavelengths in the visible to infrared range. Over time, detailed studies into materials and their interaction with different bands of light took place. After identifying the spectral absorption properties of crucial materials, the resulting data enables automated systems to differentiate between materials across countless applications. The broadband LED light sources work alongside photodetector sensors and spectral imaging cameras in order to identify materials present.

Applications include detecting the presence and quantity of water in an object, such as in optical food sorting applications, or identifying whether or not a medicine bottle has been filled to the correct level. The material properties within a plant shift throughout its various stages of growth, and categorizing this information can allow us to teach an automated system to send an alert when the plant is primed for harvest.

If you want to simultaneously identify multiple materials, each with a different peak light absorbency, it is possible to deploy separate LED and sensor packages to illuminate each respective material. Incidentally, multi-chip SWIR packages can house up to three narrowband chips, each emitting a different wavelength.

A perk of broadband LED light sources, however, is that they are able to emit a wider range of wavelengths simultaneously. By using sensors that are sensitive to certain wavelengths, it is possible to identify multiple materials within a substance, while only using one broadband light source. Not only does this technique make it possible to recognize multiple contents within an object, the data gleaned from the analysis can provide accurate quantitative measurement.

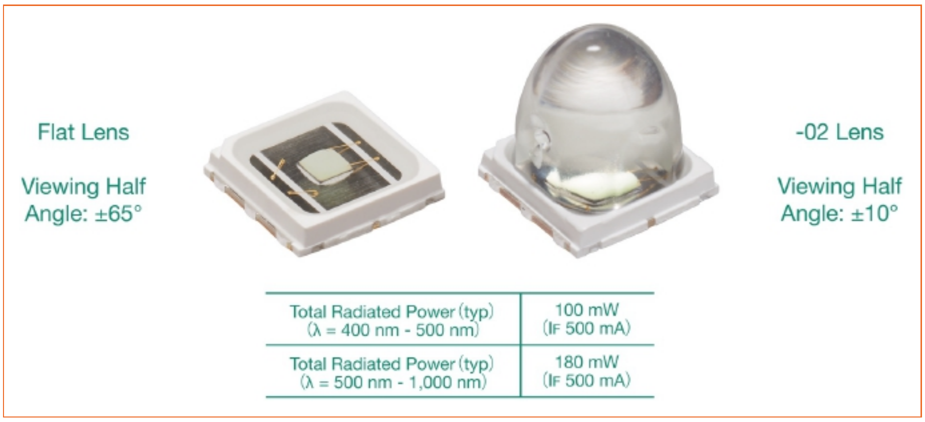

Figure 1: Broadband LEDs with lens options and output power.

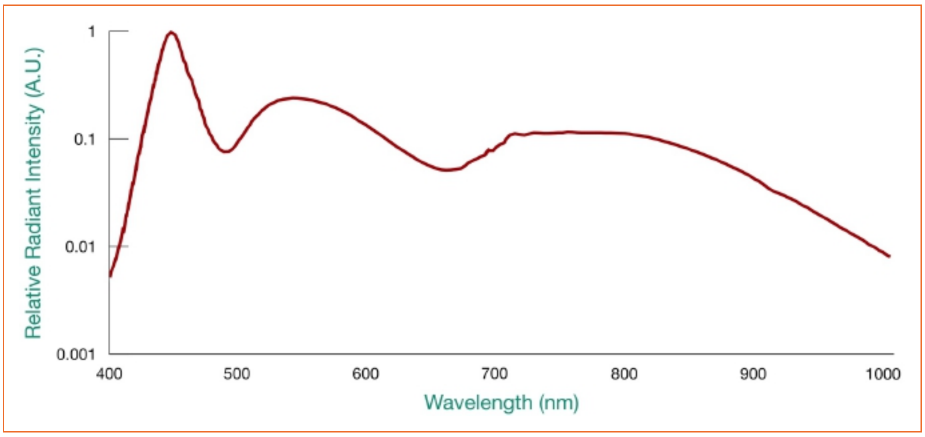

Figure 2: Relative spectra emission of Broadband LEDs.

Application	Targeted Materials
Food Inspection	Water, sugars, proteins, fats, carbohydrates, etc.
Pharmaceutical Inspection	Lactose, cellulose, starch, etc.
Plant Growth Monitoring	Water, chlorophyll, carotenoids, anthocyanins, etc.

Table 1: Examples of materials detected by Near-Infrared Spectroscopy.

NIR vs SWIR LED Technologies

Factors that will influence your choice between visible-to-NIR broadband, NIR only, and multi-chip SWIR LED spectroscopy include the target materials, the peak light absorbency of those materials, and the available budget.

Firstly, the clear division between the NIR and SWIR wavelength bands reflects in the respective use of CMOS and InGaAs sensors. CMOS sensors can mitigate any budget impact, which is why they are the most commonly used photo-sensors, line image sensors, and area image sensors. CMOS sensors are widely available and are relatively cheap compared to the indium gallium arsenide (InGaAs) sensors required to detect wavelengths in the SWIR band.

InGaAs sensors are more expensive than CMOS, but currently suffer from inferior spatial resolution. Due to a minimum pixel size of 10 µm, an InGaAs sensor cannot capture images in as much detail as a CMOS sensor, which features pixels of only 2 µm. Despite this, InGaAs sensors are currently the only option for those who wish to capture spectral images in the 1000–1800 nm SWIR range.

While budget limitations arise from the sensory components of a device, the key to fast and accurate inspection is the responsibility of your light source's output power. NIR and SWIR cover a broad wavelength range which is quite weak in terms of absorption, and requires multi-variate analysis to detect materials. Therefore, high power illumination is essential to ensure the sensors are able to pick up viable absorption data. LED manufacturers, such as Ushio, have been persistently breaking output records in recent years. With rapid development across all wavelength classes, a highly competitive market has emerged, where each producer battles to install itself as the leading high-power LED collection on the market.

Applications for Broadband Visible-NIR LEDs and Narrowband SWIR LEDs

Whether your application requires broadband illumination or a multi-narrowband-chip SWIR solution, infrared LED technology can open possibilities in a multitude of applications:

- Automatic Number Plate Recognition (ANPR)
- Biological tissue characterization
- Biometrics
- Blood-oxygen saturation analysis
- Counterfeit detection
- Endoscopy
- Foreign matter detection
- Hyperspectral imaging
- Machine vision
- Material identification
- Medical sensors
- Moisture content measurement
- Mineral exploration
- Night vision
- Optical sorting
- Photo-dynamic therapy
- Plant growth monitoring
- Produce inspection
- Quality control / quality assurance
- Retinal scan and OCT-Angiography
- Spectroscopy
- Sun simulation
- Wafer inspection

Spectral Absorption Measurement Systems which use Spectro Broadband LEDs

While a broadband LED can form a crucial component of any spectral absorption measurement system, the light source will only take you half way. At the other end of your process, a detection component is essential to convert the broadband light into useable data. The two most common solutions are sensors, also known as photodetectors, and spectral imaging cameras. Here, we will explain the fundamentals behind the two most popular broadband spectral absorption measurement systems:

Spectrum Measurement

This type of system makes use of a spectrometer, a sensory tool for measuring the wavelength and frequency of light, in combination with a broadband LED. The spectral absorbency of certain complex components, such as those present in foods and medicine, are analyzed using a mathematical and statistical science known as chemometrics. Chemometrics is the process of extracting individual quantitative datasets from multi-faceted chemical systems.

An ideal light source for combination with a spectrometer, Ushio's Spectro broadband LED series delivers high irradiance, broadband illumination in the visible to infrared region, and a stable emission spectrum. These characteristics are essential to guarantee that the spectrometer receives everything it needs to produce accurate spectral measurements.

Spectral Imaging

Spectral imaging cameras have introduced a new era of spectral absorbency measurement. The use of a spectral imaging camera allows the analyzed object to be broken down into pixels. Each pixel contains its own spectral data, which can be independently analyzed. The spectral imaging camera works by capturing the x-axis' line image with an area image sensor, which distributes the resulting image spectrally. Perpendicular to the y-axis, the imaging object being imaged is scanned to capture a 2D spectral image.

Once again, broadband LEDs are an ideal companion for a spectral imaging camera. The high irradiance, broadband illumination, and stable emission spectrum of the guarantee that the camera receives all the data needed to produce a detailed spectral image for analysis. ■

	NIR: 700 nm - 1,000 nm	SWIR: 1,000 nm - 1,800 nm
Sensor Type	Wavelength range detectable by low-cost, common CMOS sensors	InGaAs sensors are required; 10 - 20 times more expensive than common CMOS sensors
Absorbancy	Very low	Low
Material Detection Ability	Absorption very weak, but broad; multi-variate spectrum analysis required for material detection	Weak spectral absorption; multi-variate spectrum analysis required; excellent detection ability when analysing condensed matter

Table 2: LEDs for Near-Infrared Spectroscopy (NIRS).

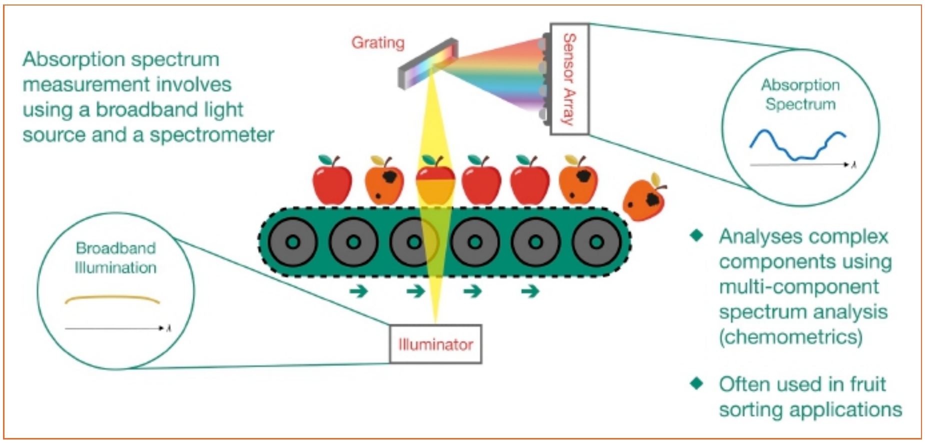

Figure 3: Absorption spectrometry with Broadband LEDs.

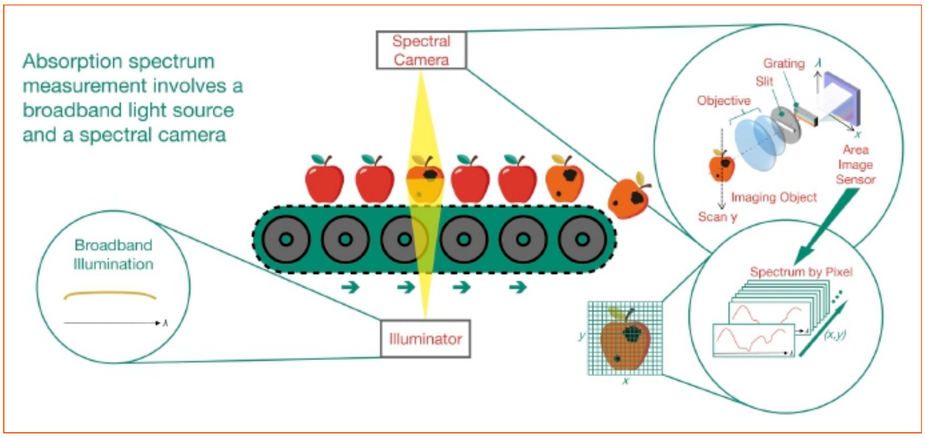

Figure 4: Broadband LED spectral imaging.

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Dimmable Non-isolated LED Driver with Highest Light Quality and Efficiency

Designers of LED drivers typically do not consider linear regulators to regulate the LED current since it is difficult to achieve high efficiency. On the other hand, linear regulators can control the LED current to be perfect DC, resulting in the best possible light quality, at least as far as the driver is concerned. Moreover, with the Active Headroom Control (AHC) architecture, a linear regulator can achieve efficiencies on par with switched-mode regulators. This article describes the design of a non-isolated driver, consisting of a power factor correction (PFC) together with a linear LED regulator stage based on Infineon's BCR601. The implementation and performance results show that this dimmable non-isolated LED driver can achieve high efficiency and best light quality at a low cost.

Non-isolated LED Driver Requirements

In many luminaires, the isolation of the LED from mains voltage is not mandatory. In this case, most often, a combination of a boost PFC with a buck as the second stage is used. As explained elsewhere [1], such a two-stage topology is the best approach to achieve compliance of input (e.g., line harmonics) and output (e.g., flicker) parameters with the mandatory standards. This trend is enforced by the light quality requirements laid down, for example, in IEE 1798 [2] and EU eco-design regulation [3]. These standards set strict limits for frequency components below a few kHz since these lower frequencies are known to cause misperception or other biological effects. On the other hand, higher frequency components can interfere with other electronic equipment such as cameras or scanners and are therefore also undesirable.

Since the light intensity of an LED is proportional to the driving current, any AC component in this current will show up as a flicker or stroboscopic effect and therefore deteriorate the light quality. Consequently, the optimum driving current is a pure DC current, free of any AC component.

Besides the quality of input current and light, the cost is another important parameter in LED driver design. In general, non-isolated LED drivers are very cost-effective. Similar to the boost-converter used as PFC in the first stage, the buck as the second stage can typically be implemented with an off-the-shelf inductor. Even if a customized inductor is needed to fulfill specific design constraints, it will be cheaper than the transformer of an isolated driver because it can be smaller and has much lower insulation requirements. A linear regulator for the LED current as the second stage can reduce the cost even further. At the same time, no inductor is necessary at all. Moreover, since there is no switching action, the effort to comply with EMI standards like EN55015 [4] may be significantly reduced as well. It is obvious that the latter can reduce development time and cost considerably.

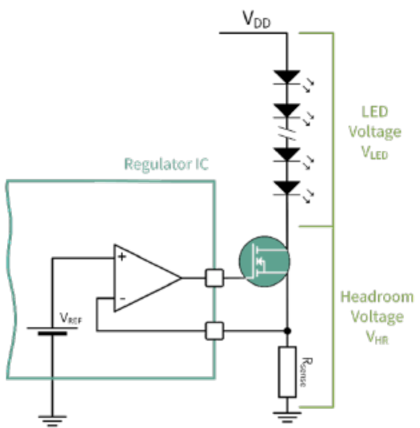

Figure 1: Simplified schematic of linear LED current regulator.

Using Linear Current Regulators on LED Drivers

Linear regulators are not the designer's first choice for higher power applications because they are rumored to achieve notoriously low efficiency numbers. However, linear regulators are a good choice in terms of light quality. Since, by definition, they don't switch, the output currents and voltages are usually free of any AC component. Also, a linear regulator can effectively suppress the ripple of double the line frequency coming from the first stage. At the same time, the regulated current can be easily reduced down to a few percent of its nominal value. This means that dimming is fully analog without any related lighting artifacts like flicker or stroboscopic effects.

Why do linear regulators tend to be inefficient? This can be easily understood with the help of **Figure** 1. The regulator IC controls the LED current by comparing the voltage drop across the resistor R_{SENSE} with an internal reference voltage V_{REF} and adjusts the gate voltage of the MOSFET so that both are equal. This results in a constant current through R_{SENSE}, as well as through the MOSFET and the LED. The headroom voltage V_{HR} is the difference between the supply voltage V_{DD}, coming from the PFC stage, and the LED forward voltage V_{LED}. The MOSFET Q_1, together with R_{SENSE}, dissipate the power $P_{loss} = V_{HR} \cdot I_{LED}$.

With a fixed V_{DD}, this power loss can be high, for example, when the number of LEDs connected to the driver can vary over a wide range. That is the case for most commercially available drivers.

But even if the number of LEDs was fixed, there is a considerable variation in V_{LED}. V_{LED} varies a lot with production lots and, potentially, with temperature, which is more important. If V_{DD} was properly selected for the corner case of the lowest V_{LED}, it would lead to excessive power dissipation in the opposite corner case.

This is why linear current regulators are typically used in applications where the LED current is small. In this case, the power dissipation is relatively small and therefore acceptable.

Active Headroom Control (AHC) for Highest Efficiency

There is a pretty obvious solution to increasing the efficiency of linear regulators: a variable V_{DD}. When V_{DD} is regulated such that there is just enough headroom voltage for Q_1 to regulate I_{LED} properly, the power dissipation is minimized, and thus efficiency can be high. This is achieved by regulating V_{HR} instead of V_{DD} itself.

Figure 2 shows how AHC is being implemented. The loss minimization is accomplished by a second feedback loop that monitors the drain voltage of Q_1 through a divider network consisting of R_D and R_S and compares the resulting signal to an internal reference V_{REF_2}. The output of the error amplifier controls an optocoupler in most cases, but, in the case of the non-isolated driver, it is also used directly to control the PFC stage. Because the first stage is a PFC, the crossover frequency of the feedback loop must be in the range of 10 Hz, which is achieved by the proper selection of C_{FB} and R_{FB}. Due to the slow loop, the average drain voltage is essentially regulated.

If the output voltage of the first stage was a pure DC voltage, the headroom could be regulated to a few hundred millivolts, just depending on the $R_{DS(on)}$ of the MOSFET, leading to negligible losses. Unfortunately, in most applications, this is not the case. Most LED drivers are supplied from the AC line and require power factor correction (PFC) to comply with EN61000-3-2 [5]. It is inherent to PFC circuits of whatever topology that their output has a significant AC ripple of double the line frequency. Whether isolated or non-isolated, the ripple amplitude V_{RIP} is determined by the output current of the PFC stage and the capacitance of the output capacitor.

Further Minimization of Linear Regulator Losses

Why is V_{RIP} so important? Simply because the voltage drop across an LED string, driven with a constant current, is also constant and varies only with temperature. When V_{LED} is constant, but the output of the first stage has an AC component, then this AC component has to drop across the Q_1. With a constant current, being the case in this application, the loss of the MOSFET is proportional to the average V_{DS}, which is dominated by the average V_{RIP}. Together with the equation of the PFC stage output ripple, the final equation for the Q_1 losses is:

$$P_{LOSS,Q1} = \frac{I_{LED}^2}{4 \cdot \pi \cdot f_{LINE} \cdot C_{OUT}} + I_{LED}^2 \cdot R_{DS(on)} \quad (1)$$

There are several strategies to minimize the losses. While minimizing $R_{DS(on)}$ only reduces the second, typically smaller, summand, it is more promising to reduce I_{LED} or increase C_{OUT} (or both). How successful the strategy of increasing the value of C_{OUT} is, becomes evident in **Figure** 3 graphs. In this example, the C_{OUT} of a 20 W low voltage driver (I_{LED} = 500 mA) was varied from 220 µF to 1100 µF. By increasing this capacitance, the ripple voltage decreases from 6.9 V_{PP} to 1.44 V_{PP}, and the efficiency rises from a good value of almost 89 percent to an excellent one which is close to 96 percent.

A significant observation regarding $P_{LOSS,Q1}$ is that it doesn't contain LED voltage, i.e., losses are independent of V_{LED}. That

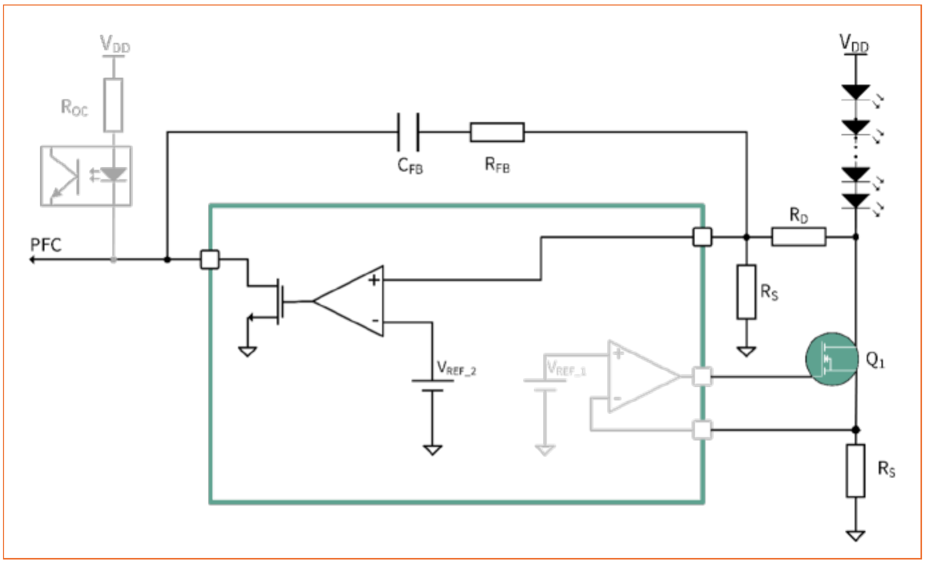

Figure 2: Second control loop to achieve AHC. The optocoupler is only needed in isolated drivers.

leads to the conclusion that for a given output power, the linear regulator approach gives higher efficiency, higher V_{LED}, and lower I_{LED}. This is illustrated by **Figure 4**, where the output power and all other driver parameters were kept constant, and the output voltage was increased by increasing the number of LEDs connected. Consequently, the current drawn from the first stage decreases. This leads to an efficiency increase from 93 percent to almost 94.6 percent.

As already mentioned, both strategies, increasing C_{OUT} and decreasing I_{LED}, can be used to achieve the highest efficiency.

Practical Implementation

From what has been mentioned so far, it seems to be a good idea to apply the linear regulator approach to a non-isolated driver with high V_{LED} and small I_{LED}. In terms of power efficiency and cost, a boost-type PFC based on a critical conduction mode (CrM) controller is an unbeatable solution for output power levels up to about 300 W. Due to the boost operation, the output voltage is always higher than the highest peak input voltage, leading to 420 V DC output in most implementations, or even more. This PFC stage is then followed by the proposed linear with AHC. A greatly simplified schematic of the above-sketched principle is shown in **Figure 5**.

The first stage can be implemented with a controller like IRS2505L and shall not be analyzed in detail. It is just essential to know that the PFC will have a full load output ripple of 10 V_{PP} to 15 V_{PP} if appropriately designed. This is important for the correct selection of the headroom voltage.

The second stage uses the BCR601 linear LED controller IC that contains the error amplifiers and references of the two feedback loops explained before, as well as some additional features. One detail that differs from the circuit described so far is that the BCR601 only needs one external resistor R_D to define V_{HR}. This is because it contains an internal current sink with a typical current of 5.5 µA that replaces the resistor R_S. Therefore, if a low measurement current is less critical than the accuracy of V_{HR}, then R_S should be used and draw a current that is higher than the one of the internal sink.

Probably the most important additional feature is the dimming of the LED through pin MFIO. As long as the voltage at this pin is equal to or higher than 3.3 V, the full LED current flows. Thus, the internal 400 mV reference, and with that, the LED current, is reduced linearly from 100 percent to 3 percent of nominal (i.e., 16 mV) as V_{MFIO} goes from 3.3 V down to 0.2 V.

When V_{MFIO} is lowered further, the current stays at 3 percent of nominal until V_{MFIO} reaches 0.1 V. Below 0.1 V, the LEDs are turned off. To prevent flicker, the circuit has a built-in hysteresis of 0.1 V, i.e., raising V_{MFIO} from below 0.1 V will turn on the LED current at 0.2 V only.

The device also contains an internal current source of typically 20 µA that are flowing out of pin MFIO. Through that, a variable resistor connected to that pin will generate a voltage at MFIO that is in the range of 0 V to 3.3 V if appropriately selected. That means that the device accepts active as well as passive dimmers.

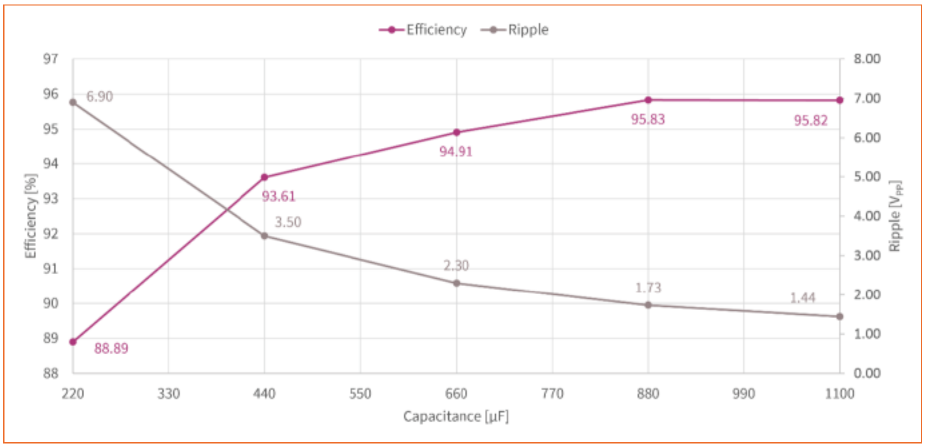

Figure 3: Efficiency of a linear regulator with AHC vs. COUT of the first stage. PLED is kept constant.

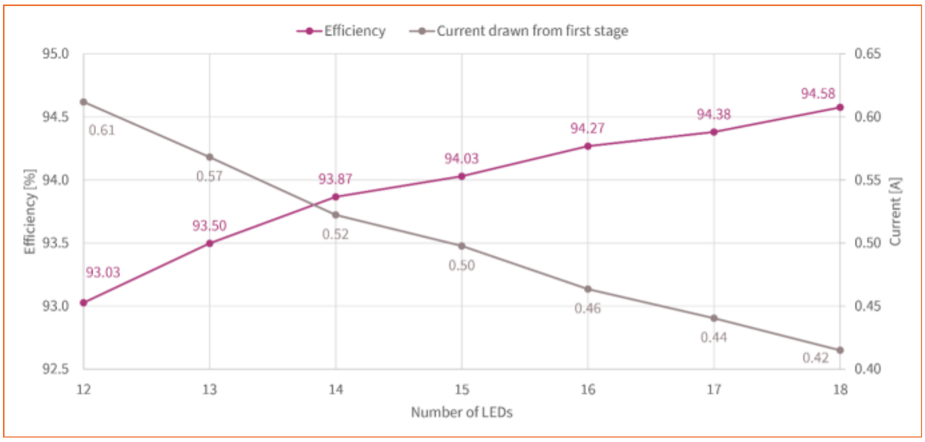

Figure 4: Increase of efficiency with an increase of VLED and decrease of ILED. PLED is kept constant.

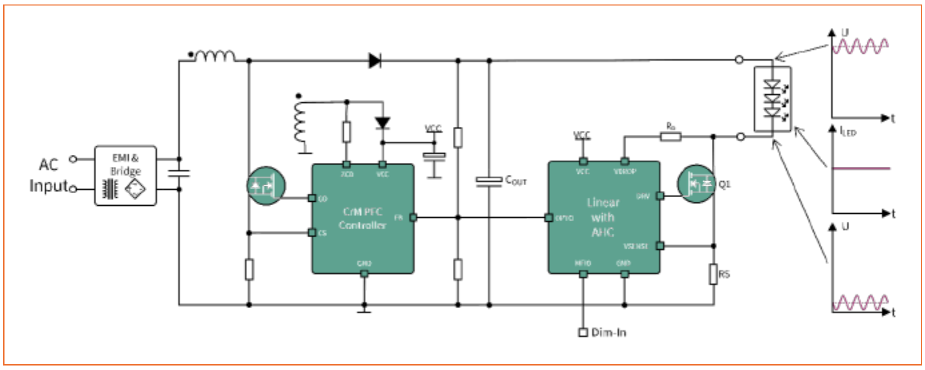

Figure 5: Simplified schematic of a LED driver based on PFC plus linear regulator with typical waveforms found at the output.

HV LED driver with BCR601

The complete schematic of the second stage can be found in **Figure 6**. R11 and R12 are the sense resistors that determine the nominal LED current of 67 mA in this case. Their voltage drop is fed through R17 and R18 to the pin VSENSE, and it is compared to the internal reference of 400 mV.

The headroom voltage is determined by R5, R6, and R7 and an internal current sink of 5.5 µA. The setpoint at pin VDROP is 0.31 V. Both together result in a V_{HR} of about 5 V. Consequently, the ripple voltage of the first stage should be below 10 V_{PP}. D10 protects the IC from voltages above 60 V at pin VDROP.

An essential feature of BCR601 not mentioned so far is the overvoltage protection that protects the application in case of an open LED. Then V_{HR} would constantly be zero, and the feedback loop would increase V_{DD} to potentially destructive voltages. This is prevented by monitoring V_{DD} through the divider network consisting of R3, R4, R10, and R13 and overruling the AHC if the level at pin OVP is above a certain threshold.

Output short circuit protection is implemented through D1, R1, and R1a, that turn off Q2 if its drain voltage is too high, which is typically the case if the output is shorted.

The supply voltage for BCR601 comes from the PFC stage and is stabilized and filtered by R14, R2, C15, C7, and D15.

The R_{set} of 470 kΩ together with the internal resistance at pin MFIO guarantees a pin voltage of at least 3.3 V which results in a full output current if no dimmer is connected to the DIM input. R9 and C4 act as a low-pass filter in case of long wires.

Finally, C5 suppresses parasitic oscillations of the LED current in the case of long connecting wires with relatively high inductance.

Performance Verification

To verify the performance of our approach, the circuit described above has been implemented and combined with a PFC based on IRS2505 as the first stage. The main focus was on driver efficiency, but the mentioned safety features have been tested as well. As a result, the driver is very robust and fully protected from output short circuit as well as open output.

The full load system efficiency (**Figure 7**), which means the combined efficiency of the PFC and regulator stage, is above 91 percent for full output power of 28 W and can even achieve 95 percent if the input voltage is 230 V_{RMS}. This is an excellent result and is difficult to exceed even for more complex topologies.

At the same time, the light quality of such a solution is unsurpassed. It has been mentioned above that the drive current of the LED is essentially pure DC, and consequently, no light modulation is measurable or even visible. Measurements of temporary lighting artifacts (TLA) have been done, using different metrics as presented in Table 1.

TLA metric	Relative output power 100%	75%	50%	25%
P_{st}^{LM}	0.0	0.0	0.0	0.0
SVM	0.042	0.042	0.042	0.042

Table 1: Light quality vs. output power.

P_{st}^{LM} and SVM are TLA metrics that are defined in the EU directive [3] and are measures for flicker and stroboscopic effects respectively. The requirements from that directive are $P_{st}^{LM} < 1$ and SVM < 0.4 at full output power of the driver. The linear regulator-based LED driver presented here

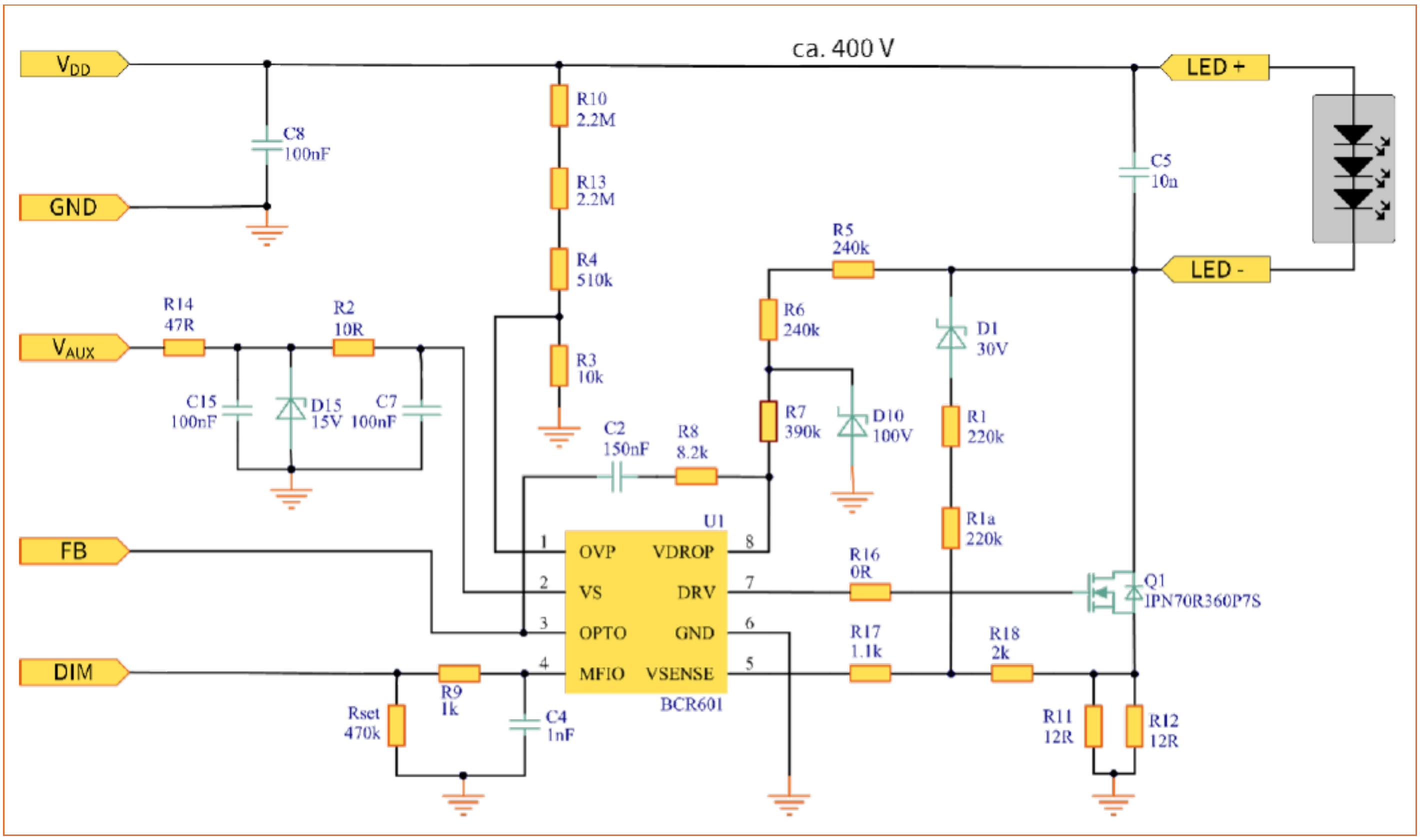

Figure 6: Linear regulator for HV LED based on BCR601.

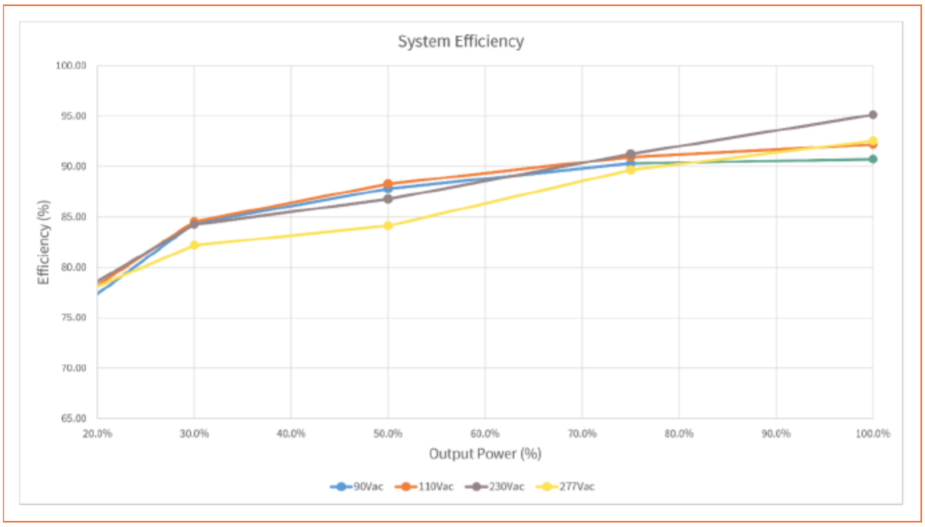

Figure 7: Total system efficiency of BCR601 reference design in combination with XDPL8219-U40W.

exceeds these requirements by far, not only at full power but in a dimmed state as well. Most switch mode regulator-based drivers use either pulse width modulation (PWM) or some kind of burst mode to achieve low dimming levels. This leads to measurable light and it can be very difficult to make such drivers compliant with IEE1789 [2]. With the linear regulator, having virtually no light modulation, this is easy to achieve.

Conclusion

Achieving highest light quality and efficiency at the same time is a challenging task when switched mode topologies are used. Especially achieving low dimming levels is almost inevitably linked with modulation of LED current and, consequently, lighting artifacts like flicker or stroboscopic effects. With Infineon's linear driver with AHC, these two seemingly mutually exclusive design goals can be achieved. With the presented approach system efficiencies of up to 95 percent are possible and light modulation is negligible. Finally, this approach allows very compact and especially flat LED driver designs that enable elegant luminaire designs. ■

More detailed information is available from these documents:
* Tunable white LED drivers with BCR601 and BCR602
* Engineering Report: 36 W dimmable and flicker-free linear LED Driver IC with BCR601
* Design guide linear LED controller BCR601

References

[1] LED professional Review (LpR), 78, S. 76-79. Luger Research e.U., ISSN 1993-890X.
[2] IEEE Std 1789:2015 IEEE Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers
[3] Commission Delegated Regulation (EU) 2019/2015 of 11 March 2019 supplementing Regulation (EU) 2017/1369 of the European Parliament and of the Council with regard to energy labelling of light sources and repealing Commission Delegated Regulation (EU) No 874/2012
[4] EN IEC 55015 Limits And Methods Of Measurement Of Radio Disturbance Characteristics Of Electrical Lighting And Similar Equipment (EN IEC 55015:2019&A11:2020)
[5] EN IEC 61000-3-2 Electromagnetic Compatibility (EMC) - Part 3-2: Limits - Limits For Harmonic Current Emissions (equipment Input Current ≤16 A Per Phase) (IEC 61000-3-2:2018/A1:2020)

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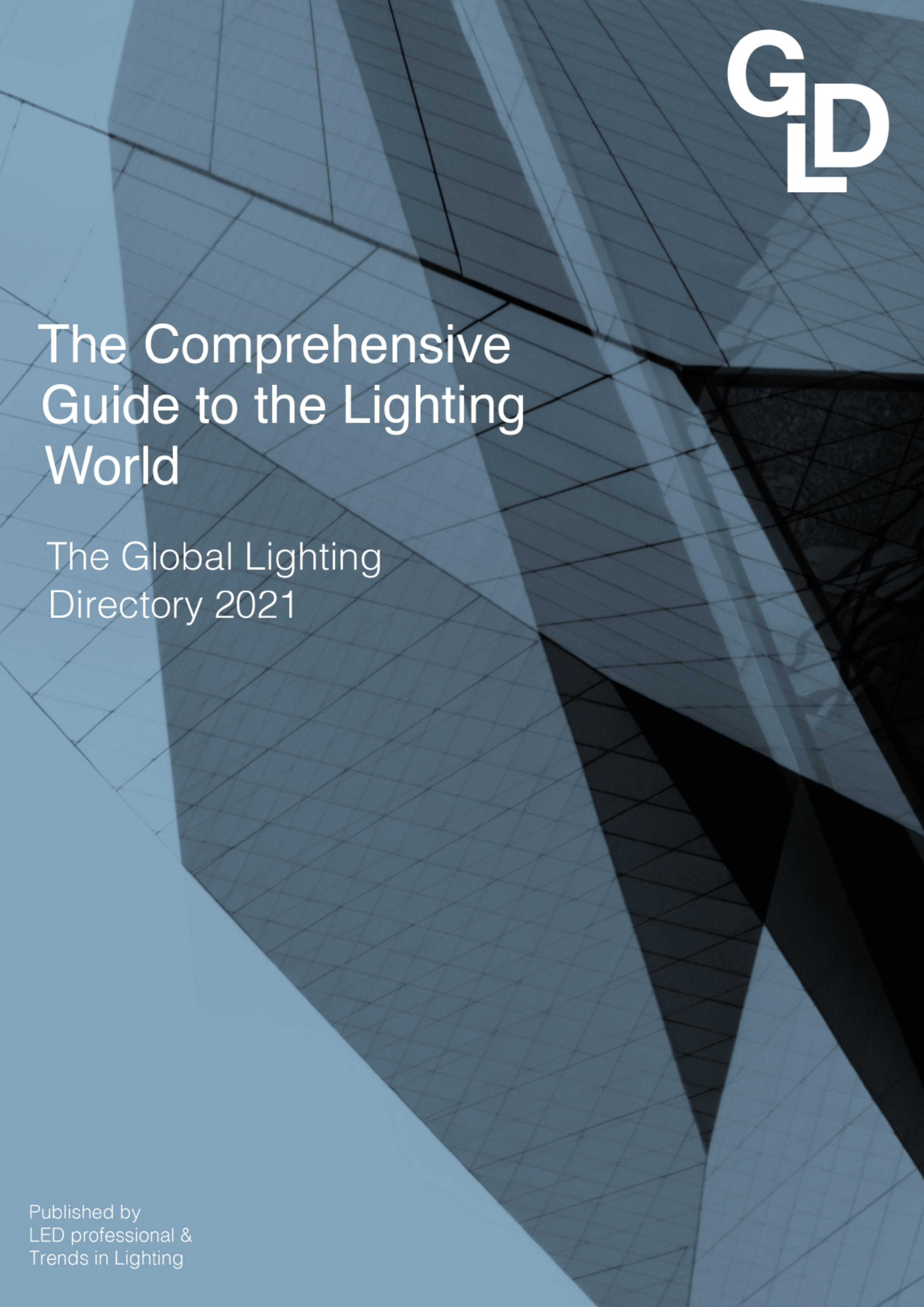

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