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LED professional Review

LpR

The Global Information Hub for Lighting Technologies

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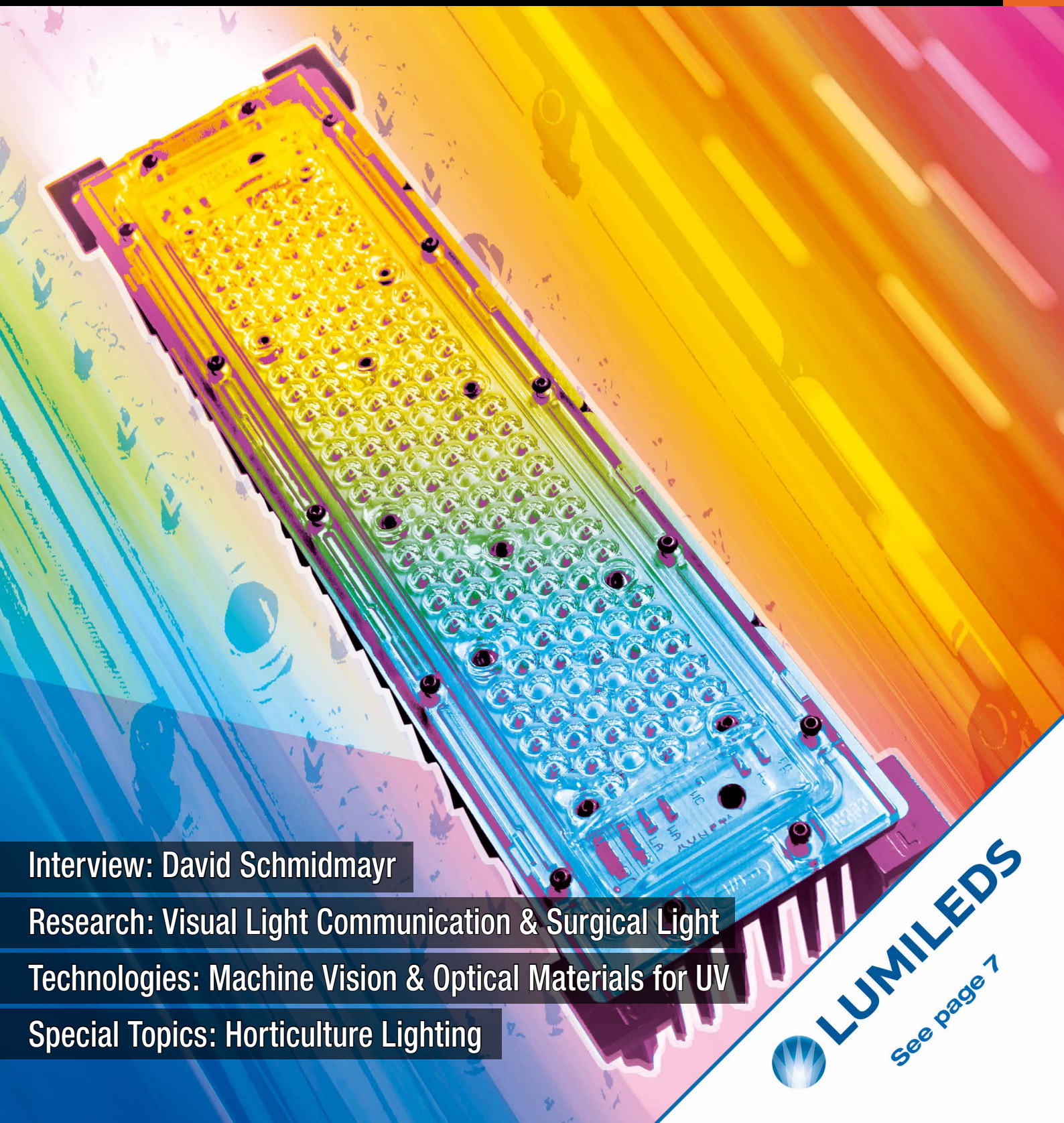

Interview: David Schmidmayr

Research: Visual Light Communication & Surgical Light

Technologies: Machine Vision & Optical Materials for UV

Special Topics: Horticulture Lighting

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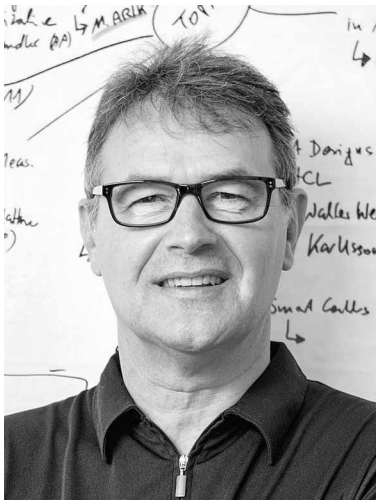

Quality of Light

Arno Grabher-Meyer, Editor-in-Chief of the LED professional Review (LpR), has summarized the latest trends and products in the post show report from LightFair International in Philadelphia.

The quality of light is at the center of the analysis and we see this as an important aspect for the coming years. The aim is to provide the right light for the respective tasks and visual needs. This applies both to Human Centric Lighting and to Horticulture Lighting.

In our Tech-Talk Bregenz series we interviewed David Schmidmayr, a Horticulture Lighting expert, to get his take on the subject.

Putting the quality of light back in the spotlight seems to be the right approach. All innovative and digital developments will help us to ensure situational and purposeful quality.

In this sense we wish you a good read and, as always, we look forward to your feedback, suggestions and critical comments!

Yours Sincerely,

Siegfried Luger
Publisher, LED professional

PS: With the new Global Lighting Directory (see www.GLD.lighting) we offer quality providers, from planners to manufacturers and service providers an international platform for their products and services. Take a look at the directory and if you don't find your company, you can submit a basic listing for free.
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COMMENTARY

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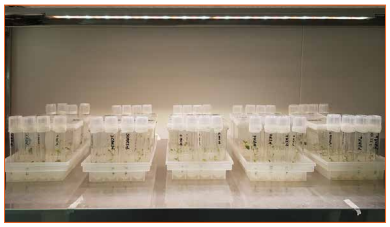

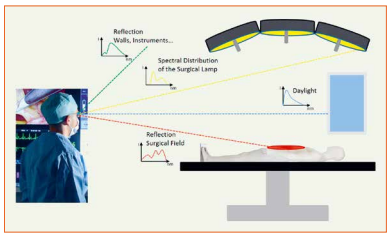

ADVERTISING INDEX

LUXEON 2835 Color Line

The best performance, the most colors

The LUXEON 2835 Color Line enables a new era of color lighting. This robust color line provides high performance and is targeted at cost effective designs. Complemented by a broad range of white offerings, the LUXEON 2835 Color Line enables RGBW applications. This product line extends the comprehensive LUXEON Color Family.

Key Benefits

- Broad range of White for RGBW applications
- Full color palette for a wider spectrum range
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Key Applications

- Architectural & Entertainment
- Color Tunable Illumination
- Emergency Vehicle Lighting
- Signage

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LUMILEDS

Patrick Durand

Patrick Durand is the Worldwide Technical Director at Future Lighting Solutions (FLS) with over 15 years of experience in the solid state lighting industry. Patrick leads the FLS Technical Marketing teams and FLS laboratory teams located in multiple regions around the world with the objective of providing world-class support to lighting OEMs in developing luminaires with the latest SSL technology from the light source to the complete system incorporating the LED driver, optic, thermal management and intelligent control solutions.

SELECTING THE UV LED WAVELENGTH FOR PURIFICATION APPLICATIONS

Recently there have been articles about how UV LED technology will revolutionize water and surface purification. However, like with every new technology (or application of existing technology in a new market), there are elements of confusion and misinformation. The key challenge for the adoption of emerging technologies is to determine the right balance between technology readiness, pricing and market acceptance. As an example, it will take several years before UV LED performance and pricing reach an appropriate level for targeting municipal water treatment. Applications for which UV LEDs are ready today include water dispensers, ice makers, tumblers, humidifiers, vacuum cleaners, medical instruments and area/hospital lighting, amongst others.

The main value proposition of UV technology is to purify without potentially harmful chemicals. UV LED technology is ideal for these applications since they are compact, instant-on, low voltage devices with superior reliability over traditional UV lamps. For water and surface purification applications, low-pressure mercury lamps are traditionally used, which have a peak wavelength of 254 nm. This has caused a significant proportion of the market to believe that LEDs must also emit light at 254 nm to be effective. The reality is that 254 nm is not the peak absorption wavelength of bacteria and viruses but is simply a convenient wavelength for mercury lamps. In fact, the peak absorption wavelength of bacteria and viruses is around 265 nm. Most UV-C LEDs have a peak wavelength between 275 nm and 280 nm and are just as effective as 254 nm for purification purposes.

For water purification, there is no debate that UV-C technology is required to eliminate the threat of bacteria and viruses. However, for surface purification, the market includes UV-C (i.e. 275nm) and UV-A (i.e. 405nm) solutions. The market perception is that 405 nm LEDs are safer and lower cost but the reality is quite different. If the required amount of light to achieve the same impact on bacteria is compared, then the perception is proven to be inaccurate. In fact, 405 nm light requires about 1200 times more light than at 275 nm, which means that due to the required light density at 405 nm, the 275 nm UV-C LED will be significantly lower cost and safer at the system level.

It's important to understand the main differences between 275 nm versus 405 nm LEDs for surface purification. The first is how organisms are affected by the different wavelengths. Light of 275 nm LEDs penetrates through the cell walls of all organisms such as bacteria, viruses, and mold where the light disrupts the structure of their DNA molecules, prohibiting reproduction, rendering organisms inert. 405 nm light targets specific chemical compounds (porphyrins) found in cells of certain bacteria to cause an oxidation reduction reaction where this does not kill the bacteria but rather inactivates them.

This means that 275 nm light is lower cost, safer and targets a wider range of organisms for equivalent performance. The main clear advantage of UV-A LEDs for luminaire designs is that UV-A light is compatible with standard diffusors, PMMA and PC optics where UV-C light requires Quartz glass or silicone optics. The bottom line is that an impractical number of UV-A LEDs are required to reach a >99.9% bacterial inactivation rate where this is easily achieved with 275 nm LEDs. Although there is a market for luminaires with UV-A LEDs providing some level of purification, with the rise antibiotic resistant bacteria infecting millions of people per year, it's clear that UV-C LEDs should be the technology of choice for surface and water purification in the years to come. ■

P.D.

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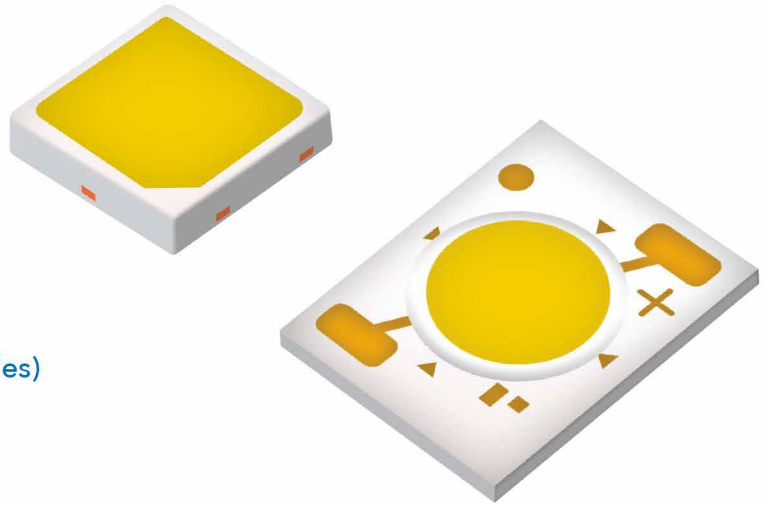
- Available in SMD 3030 packages (757Series) and various Chip on Board models



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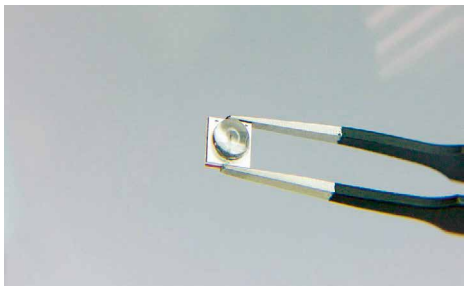
Violumas improved output for their UVA 320-410 nm LEDs

Violumas recently announced a 30% increase in optical output for all UVA SMDs. This increase can be attributed to their "Index Match" technology. The standard product line has a default radiant angle of 60°, and custom optics can be fitted for angles of 30°, 60°, 90°, 120°, and flat. Violumas first revealed its surface-mount-device (SMD) product lineup with a focus on thermal dissipation at RadTech 2018.



Violumas improved output for their UVA 320-410nm LEDs

Updated Specifications:
Mid Power Series (VS5252C1L6):

Wavelength (nm)	Typ. Optical Output at 700 mA (mW)	Forward Voltage (Vf)
405	1285	3.7
395	1280	3.7
385	1300	3.9
375	930	3.9
365	775	4.1

High Power Series (VS7272C4L6):

Wavelength (nm)	Typ. Optical Output at 700 mA (mW)	Forward Voltage (Vf)
405	4900	7.4
395	4700	7.5
385	4650	7.6
375	3300	7.8
365	2850	8.2

Violumas' unique 3-PAD SMD structure optimizes heat dissipation from chip to heat sink via specialized thermal pillar MCPCB. Violumas SMDs have thermal resistance of 0.9°C/W, which is the lowest on the market. Because Violumas' SMDs exhibit exceptional thermal resistance, they can be driven at higher currents without experiencing dramatic thermal decay. In regular applications, this directly corresponds to increased reliability and life span.

But interestingly, Violumas' industry-leading thermal characteristics make their products ideal for high power applications with extreme wattage and cooling requirements, opening up the possibility for new applications and deployments.

Violumas has also updated the form factor of the Mid Power Series by reducing the footprint from 6.0x6.0 mm to 5.2x5.2 mm. The High Power Series increased in size from 7.0x7.0 mm to 7.2x7.2 mm for improved accuracy when placing the lens.

In addition to high performance UV LED packages, Violumas is unique in manufacturing custom SMD and COB modules for 3D printing and epoxy/ink applications that require high wattage and uniformity requirements. Violumas also provides services in thermal management solutions and can offer full-system UV LED integration for unique 3D printing and curing projects. ■

SETi and Seoul Viosys - Advanced Horticulture UV LED Technology

Sensor Electronics Technology, Inc, (SETi), a division of Seoul Semiconductor and Seoul Viosys showcased the LED industry's first product line encompassing the entire UV spectrum from 225 nm to 405 nm, developed for a range of applications, including horticultural lighting to enhance plant growth cycles and control diseases at LIGHTFAIR International 2019.

UV LEDs are expected to play a major role in pest control in horticulture applications in the future. SETi and Seoul Viosys are providing the broadest range of UV LEDs

"LIGHTFAIR is an ideal venue for us to showcase our latest UV LED innovations, and to introduce the larger lighting community to the technology advances that UV LEDs are making in horticultural as well as industrial applications," explained Dr. Peter Barber, director of business development for SETi and Seoul Viosys in the Americas.

"We recently presented a webinar on the use of UV-B LEDs to increase secondary plant metabolites, increase resiliency to powdery mildew and mold, and extend the post-harvest shelf life of produce," explained Dr. Barber. The one-hour webinar, entitled "Next Evolution in Horticulture Lighting," is now available on-demand. ■

Osram Quantum Dots Make LEDs Even More Efficient

Quantum Dots (QD), an innovative, tunable light conversion technology is now being used for the first time in the Osconiq S 3030 QD mid-power LED from Osram Opto Semiconductors. It marks the first step towards new LED components for the general lighting market. Osram's new mid-power LED Osconiq S 3030 QD was specially developed for area lighting and downlight applications and will empower customers to realize luminaires with high efficacy and excellent color rendering.

New conversion technology delivers outstanding efficacy, even at high color rendering indexes with the Osconiq S 3030 Quantum Dot

QDs are nanometer-sized semiconductor particles, which means they are about 10,000 times smaller than the diameter of a human hair. Due to their very small size, the light that is re-emitted when blue LED light hits the nanoparticles depends on the size of the particles. For example, QD particles that are roughly three nanometers in size produce green light, while particles around seven nanometers emit red light.

When manufacturing conventional white LEDs, the main objectives are efficacy and product quality. Considering both at the

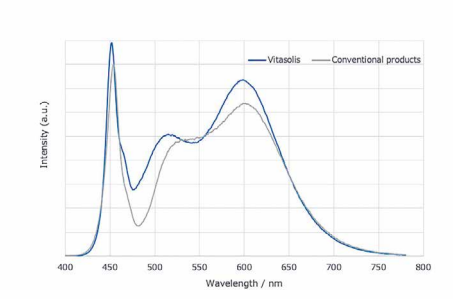
same time poses a particular challenge, especially with very high color rendering indexes (CRI), where developers with conventional converter technology have, at times, reached their limits. QDs can solve this problem. The great advantage of using these nanoparticles is that the existing LED manufacturing processes remain the same. QDs are simply used instead of conventional phosphors when the converter material is applied.

More than a year ago Osram acquired Pacific Light Technologies (PLT), a leading company in the development and manufacturing of high-performance optical nanomaterials. The PLT QD technology enables Osram to begin to close the efficacy gap that exists between CRI 80 and CRI 90 LEDs today. The new Osconiq S 3030 includes a specially developed QD phosphor solution that enables CRI 90 to achieve an outstanding efficacy value of 173 lm/W at 3000 K - a best-in-class value for 0.2 W high-performance LEDs. The compact dimensions of 3.0x3.0 mm and the low thermal resistance enable simple system design. The Osconiq S 3030 QD is also available in various color temperatures from 2,700 to 6,500 K.

Another unique feature of the PLT QD technology is that the Quantum Dots are encapsulated to protect them from moisture and other external influences that pose the greatest risk to the functionality of an LED. The special encapsulation technology allows the QDs to reliably master the demanding conditions of on-chip operation within the LED component. ■

Nichia's Vitasolis Enables Breakthrough Human Centric Lighting

Nichia Corporation unveiled a state-of-the-art LED spectrum technology, called Vitasolis at LIGHTFAIR International (USA, May 21 -23). This technology, which will be first incorporated in Nichia's market leading 757 platform, will help control human circadian rhythm via a unique spectrum meant to stimulate activity. While Nichia previously presented the technology at The Phosphor Global Summit 2019 as well as the 2019 Department of Energy SSL R&D Workshop, Vitasolis was on display at LIGHTFAIR International at Nichia's Booth.



Comparison of the 4000 K spectrum from Nichia's new Vitisolis and a conventional 4000 K white LED

Until now, the primary goal of LED lighting has justifiably been energy savings. However, recently the focus in many lighting applications has shifted towards improving the quality of light as well.

With over 50 years of phosphor experience and research, Nichia Corporation is strongly engaged in contributing to society through lighting, including improving the quality of light ("AKARI"). The innovative Vitasolis technology is another example of Nichia's contribution, now through human centric lighting.

Recent research has further revealed the relationship between light and human behavior. Humans not only recognize brightness and color of light, but human circadian rhythm can be affected by different wavelengths, especially the cyan region. For example, lighting can have an influence on activity levels throughout the day, including waking up in the morning, being active during the day, and encouraging sleep at night. While Vitasolis provides a very natural white color, part of its spectrum contains a larger amount of energy in the cyan region, which helps control the human circadian rhythm. The unique spectral distribution of Vitasolis cleanly illuminates objects while maintaining a high luminous efficacy.

The benefits of the Vitasolis technology provide a great opportunity for adoption in offices, schools, hospitals, and other locations that can benefit from improving circadian rhythm. Nichia envisions manufacturers combining Vitasolis into IoT systems and providing suitable lighting based on the time of day and desired environment. Nichia is confident that Vitasolis will truly enable the ideal human centric lighting experience. ■

Luminus Devices Pico-CoBs - Smallest LES for Tiny Light Fixtures

Luminus Devices is expanding its Gen4 LED CoB portfolio with two new Pico-CoBs with high-output and very small light emitting surfaces (LES) that enable spotlights with compact form factors, narrow beam angles, and high center beam candle power.

Luminus adds new Pico-CoBs to their CoB portfolio (image): Directional lighting gets smaller and brighter than ever before

Small, 6 mm LES, CoBs are typically limited to approximately 9 degree viewing angles. Luminus' new Pico-CoBs enable fixtures

with viewing angles as narrow as 5 degrees and produce high flux density, or punch, that is so important for high quality-of-light directional lighting applications for museum, residential, hospitality, and other environments. The CXM-3 has an LES of 3.5 mm and produces up to 675 lumens of 90 CRI 3000 K light, which makes it an ideal replacement for a 50 W halogen spot. The CXM-4 has an LES of 4.5 mm and generates up to 1255 lm, and as with all Luminus CoBs, these new devices are specified and 100% factory tested at a junction temperature of 85°C, to ensure performance and consistency that meets the users' expectations in real-world application conditions.

"Our Pico-CoBs with Gen4 technology really get luminaire designers excited because they can leverage our higher max case temperatures and max drive currents to create innovative new designs with smaller form factors," said Tom Jory, VP of Illumination Marketing at Luminus Devices. "This means lighting designers can specify luminaires with our Pico-CoBs and create unique dramatic effects with longer throws and narrower beams produced by tiny fixtures incorporating sleek designs that are hidden in the architecture." ■

Lumileds Luxeon Fusion - Next Step in Human Centric Lighting

Lumileds launched Luxeon Fusion, a breakthrough platform technology that delivers unprecedented white color selection while streamlining fixture manufacturing.

Luxeon Fusion pioneers white light tuning and selection with a simplified fixture manufacturing process that speeds product fulfillment and mainstream adoption

Combining the needs of many tuning technologies, including dim to warm and dynamic tuning for human centric lighting, Luxeon Fusion addresses color temperatures from 1,800 K to 10,000 K with high color-rendering index (CRI) (>90 over 95% of range) and high color fidelity. Customers who previously were forced to rely on disparate solutions to achieve the desired results can now leverage the Luxeon Fusion platform technology which unites white color selection, dim to warm capability, SKU reduction and dynamically tunable white lighting - all designed for mass adoption, in one single solution.

Human Centric Lighting Applications for Luxeon Fusion:
Luxeon Fusion enables the next step in human centric lighting. When lighting hospitals, restaurants, offices or retail venues, designers often wish to adjust color temperature on-site or program it to adjust light levels throughout the day to complement a changing ambient environment. Available on the Lumileds Matrix Platform, which custom configures Luxeon LEDs and Advanced Technologies on substrates to fit manufacturers' specific requirements, Luxeon Fusion is easily integrated with a variety of wired and wireless (e.g. Digital Addressable Lighting Interface (DALI), Digital Multiplex (DMX), Wi-Fi) approaches for on-demand tuning.

"White light tuning in the past was limited and could not, for instance, tune along the blackbody curve or just below the blackbody curve, a range that enables vivid color depiction," said Matt Everett, Senior Director of Matrix Platform Integrated Solutions. Programming in such ranges is enabled by Luxeon Fusion.

The first implementation of Luxeon Fusion involves modules for downlights, spotlights, troffers and linear applications – achieving system efficacy and color stability comparable to that of Luxeon LEDs. "We boosted LED utilization by 25 to 100 percent over standard two-LED or three-LED solutions, and achieve consistent light output over the tuning range – something customers value and other color tuning systems struggled to deliver," said Greg Tashjian, Senior Director of R&D at Lumileds.

A significant advantage to the Luxeon Fusion is more efficient fixture development. For instance, a fixture that is offered with CCTs (correlated color temperature) of 2700 K, 3500 K and 5000 K color temperatures, each with specific light engines and SKUs can now utilize one engine for all the fixtures and CCT can be set later - even after fixture installation. Another use involves high-impact retail environments, where companies select a signature CCT and brand all stores worldwide with one color tone. ■

Tridonic's New LED Modules Display Food, Clothing and Art in Faithful Colors

When it comes to the presentation of goods, merchandise and works of art, the right lighting helps to create a special atmosphere and to delight viewers. However, different products, materials and colors require specific lighting moods. Tridonic offers a wide range of products for special lighting tasks, with the new LED modules in the seventh-generation SLE excite (EXC) series meeting the criteria for demanding applications in food, fashion and art.

Tridonic's latest LED modules are not only perfectly matched colors for shops, retail areas and galleries, but are also powerful and efficient

Whether it's freshly baked goods, colorful textiles or valuable works of art – Tridonic's broad portfolio of LED modules offers the right light for any object: warm, intense browns for pastry displays, rich reds for the meat counter and true-color light for the presentation of fashion collections and works of art. The light colors used display fashion, food and art in the best possible way.
All the components are selected and developed in a strict qualification process. Patented phosphors optimize the interplay between efficiency and color rendering.
"The SLE G7 excite module series for spotlight applications offers our customers a wide selection of light colors which fulfill a variety of lighting tasks for presenting goods and merchandise," explains Bertrand Leplay, Product Manager Lighting Components at Tridonic. "This allows them to create varied and impressive designs in shops, exhibitions, hotels and museums."

Perfectly matched light colors for shops, retail areas and galleries

Individual color temperatures allow for food to be displayed to best effect. The colors are perceived more intensely without losing their natural characteristics. The right light is chosen depending on the reflectivity of the goods. In the FOOD series the colors of Gold, Gold+, Meat, Meat+, Fish and Fruit are available. Gold and Gold+ use intense shades of brown to underline the fresh, crisp appearance of baked goods and the variation in the range of cheeses, with Gold+ making colors look even more intense and rich. Meat and Meat+ ensure suitable presentation of fresh meat and sausages. Rich shades of red bring out the range of delicate pink to deep red, with white elements remaining white. Very cold light, in contrast, ensures fish and seafood appear fresh, while fruit and vegetables look particularly appetizing in warm white light. Since the LEDs are free from UV radiation, there is no danger of discoloration.

Fashion shops benefit from the properties of the FASHION module, which makes textiles appear in their true, vibrant and natural colors thanks to its special spectra, creating brilliant colors through warm, pleasant, high-saturation tones. The new PURE WHITE light color brings out white tones to create a rich color effect giving clothes a vivid appearance thanks to a spectrum which is below Planck curve.

Art and culture depend on the way they are presented – and light is a major factor. The ART light color puts exhibits and objects center stage and highlights their natural colors. The excellent color rendering and quality of light is produced by Tridonic's full-spectrum technology – with average values of CRI 97. Maximum color consistency (MacAdam 2) is guaranteed, and the LEDs are particularly gentle on the works of art.

Optimized generation: efficiency, lifetime and thermal management

Continuous development and improvement are of great importance at Tridonic.
The seventh-generation modules are more efficient in comparison to the previous version: thanks to a chip upgrade they now deliver up to 191 lumens per watt, making them up to 16 percent more efficient. The improved process for applying the phosphor layer also results in optimized thermal management. This means that the modules can be operated with currents of up to 2,000 mA throughout the entire temperature range, reducing the need for heat sinks. At up to 55,000 hours, the modules also achieve a significantly longer life. ■

Tridonic LLE Advanced 5 - Freedom of Design for Efficient Linear and Area Luminaires

The fifth generation of the LLE ADV series offers an amazing improvement in efficacy and new features for modules with widths of 16 mm and 55 mm. 16 mm modules are now available in 70 mm lengths, and 55 mm modules are now fitted with holes for greater compatibility with commercially available lenses.

Tridonic's LLE ADV modules of the fifth generation offer an impressive boost in efficiency and a high degree of flexibility

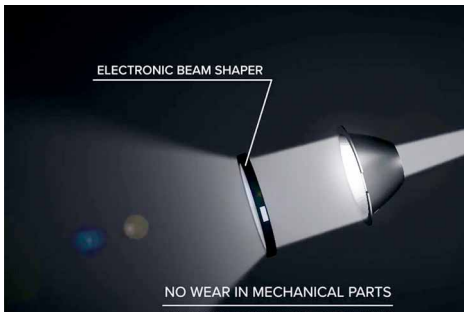
The two module series are most suitable for offices and educational establishments. They have an impressively high module efficiency of up to 190 lm/W and are extremely durable with a life of 72,000 hours. The LED modules are available with different color temperatures from 2,700 to 6,500 K, in each case with a color rendering index Ra > 80. Together with their narrow color tolerances corresponding to MacAdam3, the modules offer excellent quality of light. The modules can be quickly and easily connected with each other via plug-in terminals. Even if several modules are connected one after the other the light always remains homogeneous.

For compact linear luminaire designs:
The 16 mm modules in the LLE ADV 5 series are designed for non-SELV operation. They offer enormous freedom of design with four different lengths of 140 mm, 280 mm, 560 mm and now 70 mm. All the module versions can be freely combined with one another, giving designers a wide range of options. The 70 mm long modules fill small gaps in lighting strips so that a continuous homogeneous effect can be easily achieved. Depending on the version, the typical luminous flux is 325 lm, 650 lm, 1,250 lm or 2,400 lm. The pitch is the same as that of the previous generation so existing installations can be easily upgraded to the latest technical standard.

Open for standard lenses:
LED modules with a width of 55 mm in the LLE ADV 5 series for linear luminaires are suitable for SELV operation. They are available in length of 280 mm with a typical luminous flux of 2,000 and 4,000 lm respectively. Repositioned holes make the 55 mm modules compatible with numerous commercially available lenses, such as those from LEDIL. The modules are also extremely easy to install: They can be wired at the back. ■

LensVector Expands Dynamic Beam Shaping Lens Portfolio

LensVector is expanding its lens portfolio with the LensVector S2F Series that enables Dynamic Beam Shaping between a 15-degree spot and a 35-degree flood. The company's first offering, with a beam angle range of 5 to 50 degrees, is now the LensVector M2M Series. Additionally, LensVector now offers all lenses in a smaller, 35 mm, option that complements the current 48 mm and 65 mm lenses.



LensVector lenses make it easier now for lighting designers, store merchandisers, and clients to digitally dial in the exact beam they want

"Ladders and replacement bulbs and reflectors have been the primary tools for changing beam size, but that no longer works in the LED world," said Brent York, LensVector CEO. "Our lenses are smart and work across all protocols and wired or wireless systems. It's easier now for lighting designers, store merchandisers and clients to digitally dial in the exact beam they want."

At LensVector's stand, the company and its partner, CDI, demonstrated Dynamic Beam Shaping and showed fixture manufacturers and specifiers how easy it is to integrate the lenses into existing and new luminaires. "From LED to driver to collimating optic and control system, CDI has evaluated how to best select and integrate all the components in a dynamic beam shaping solution," said John Williammee, CEO of CDI. ■

Fulham SIG-Qualified Bluetooth Mesh Lighting Control System

At LightFair 2019, Fulham presented its new LED luminaire EliteControl hardware/software solution that uses Bluetooth mesh for wireless lighting control. The wireless luminaire control system includes an LED driver with a Bluetooth mesh interface, a new SmartBridge device for retrofitting luminaires with Bluetooth mesh controls, and an iOS commissioning app. All of Fulham's Bluetooth mesh solutions have been qualified as interoperable by the Bluetooth Special Interest Group (SIG).

Fulham's SIG-Qualified Bluetooth hardware and software delivers simple and efficient control over LED lighting

Wireless lighting controls provide an extensible, cost-effective way to provide dimming and other luminaire controls using a Bluetooth mesh network. Bluetooth mesh is secure, scalable, and provides-out-of-the-box connectivity. With a Bluetooth mesh ecosystem in place you can control luminaires with wireless light switches, sensors and other Bluetooth-enabled components from a laptop to handheld devices.

"We are getting more requests from distributors and OEMs for wireless controls for luminaires, especially for retrofit projects," said Alvaro Garcia, Senior Director, Product Management for Fulham. "We now have SIG-qualified Bluetooth driver modules, bridges, add-on sensors, and even commissioning software. At LightFair we will be showing how you can create an entire luminaire control infrastructure using Fulham's Bluetooth mesh products."

The WorkHorse LED Connected Driver is Fulham's 40W, Bluetooth-ready LED driver with 0-10V dimming. It can be installed as a conventional LED driver and then enabled for Bluetooth mesh by adding an intelligent SmartLink module. Once the SmartLink is connected, the driver is compatible with all third-party SIG-qualified wireless devices such as wall switches and sensors.

To upgrade installed LED luminaires, Fulham has developed the Bluetooth 0-10 V SmartBridge. The SmartBridge can be connected to a previously installed 0-10 V LED luminaire to add wireless control capabilities. Since it is SIG qualified it can be added to any SIG-qualified Bluetooth

mesh ecosystem without disruption. The SmartBridge is ideal for luminaire retrofits, as well as OEMs seeking to develop their own Bluetooth products.

An add-on sensor, the Link and SmartLink+, can be plugged into Fulham Bluetooth products to add motion and light harvesting controls. The sensor is designed to integrate into a Fulham Bluetooth driver or bridge and add automated lighting control support based on room conditions.

Fulham also has developed its own iOS app, eliteBlue, for commissioning, customizing, and monitoring mesh-connected luminaires. eliteBlue can run on iOS-compatible handheld device to customize lighting control parameters commissioning for lighting zones to meet site-specific needs and building energy codes.

To help OEMs, distributors, and installers get started with Bluetooth mesh, Fulham also has the Bluetooth Mesh Lab Kit. The Kit includes a Fulham SmartBridge, an EnOcean double rocker Bluetooth switch, a 9 W Vision LED engine, an iPad with Fulham's eliteBlue commissioning app installed. ■

Bridgelux Vesta® Flex - Interoperable Lighting and Controls Solution

Bridgelux announced Vesta® Flex, an innovative family of dual channel LED drivers and control modules designed to simplify and reduce the cost of connected tunable white luminaires. Immediately compatible with industry standard wired and wireless lighting control protocols including Wi-Fi, Bluetooth, Digital Addressable Lighting Interface (DALI) and 0-10V, the Vesta Flex system enables simplified, future-ready design flexibility for OEM luminaire manufacturers to meet the needs of their end customers without requiring redesign or recertification.

The design flexibility of Vesta Flex includes separate control modules and drivers that are connected using a CAT5 network cable through a robust RJ45 terminal. This structure allows customers to select their protocol of choice, luminaire manufacturers to quickly react to the needs of multiple lighting projects and allows Bridgelux to expand into additional protocols in the future. All Vesta Flex control options provide independent tuning of intensity and correlated color temperature (CCT). Customers will never again feel locked in to a proprietary system or obliged to just one standard or protocol.

Bridgelux Vesta® Flex connects life and light through a simple, flexible driver and control system

Components within the Vesta Flex family available now include:

- 30 W and 60 W brick and 60W linear driver options with NFC-programmable maximum currents and dimming curves, including smooth dimming to 0.1% and dim-to-off options
- Bluetooth mesh control module operating on Bluetooth Low Energy (4.2) protocol for industrial grade intelligent mesh networking managed through a mobile app
- Dual mode Wi-Fi and Bluetooth control module for luminaire management and communication with sensors, also managed through a mobile app
- Dual channel analog control module for CCT tuning and intensity dimming using a linear tuning range of 1.0 to 9.0 VDC, compatible with current sourcing or current sinking control devices
- DALI DT8 control module for CCT tuning and intensity dimming functionality, also compatible with industry standard current sourcing or current sinking control devices
- Complete compatibility with Bridgelux Vesta Series Tunable White array and linear LED light sources with tuning ranges from 2700 to 6500 Kelvin (K)

"Providing flexible solutions is all about removing obstacles so people can experience the benefits of human centric lighting. With Bridgelux as their single supplier, our customers now have access to an interoperable family of plug-and-play control options guaranteed to work with our high-quality light engines out-of-the-box and to simplify their entire design process," said Tim Lester, Bridgelux CEO. Vesta Flex was demonstrated at LightFair International in the Bill Brown Sales booth. Vesta Flex driver and control parts are now available for sampling. Vesta Series Tunable White array and linear light sources are available for sampling and ordering. ■

Kinglumi Unveils TUV ENEC LED Independent Control Gear - LEDGear™ Including DALI-2

The LEDGear™ new ECGs pack state-of-the-art technology and all the functions of premium performance into the compact spaces. Designed as a family of independent and quick installation compact constant current LED ECGs, LEDGear™ is qualified by TUV ENEC, CE, CB, SAA, C-tick RoSH and DALI-2. They provide you great value.

Kinglumi LEDGear independent control gear for luminaires offer state-of-the-art technology and premium performance

Easy & Quick Connection:
The LEDGear™ equipped with a push-fit strain relief cap, which allows no tool for wiring and without any screws. No Junction box (connection box) is required thanks to the independent design. The large wiring space and push type terminals also improve the experience of installation. What's more, the terminals allow the looping function to reduce more labor cost.

Outstanding Dimming Performance:
The dimming functions are designed and tested according to the most popular dimmers in Europe and Australia local market. There are DALI-2 Push-DIM , Phase-cut(Triac, ELV) dimming, ON/OFF, 0-10V dimming functions options with outstanding dimming synchrony and compatibility.

DALI-2 & Push Dim:
As a DALI member, the LEDGear™ DALI-2 ECGs are compatible with universal DALI masters/application controllers, which were tested by DALI house according to IEC

62386 Part 101,102(DALI-2), 207. In addition to the usual wide operating window by DIP switches, it also can be DALI programmed to allow current adjustable by configurator software at luminaire manufacturers. It is equipped with built-in permanent memory for DALI-2 and Push-DIM, which ensure that light returns to the previous dimming level when switched off and on again.

Compatible with Passive or Active 0-10V Dimmers:
There are passive and active 0-10V dimmers on the market, but not all the 0-10V ECGs are compatible for both, especially the active dimmers. This is because the output voltage of active dimmers is not exactly in 0-10V range. It has a tolerance, and might be over 10V (some even reach 11.2V).

Reliable Quality & Long Lifespan:
Powered by world top IC brands, like NXP and iWatt, LEDGear™ protected by glow wire tested 650°C for 30S and 850° for 5S polycarbonate housing. It's very safe for humans, as the circuit design is based on short-circuit-proof with safety insulation, and output Extra Low voltage. Long term quality testing based on -30°C /+50°C thermo cycling test at both Min & Max output.

Emergency Lighting:
Suitable for emergency escape lighting systems according to EN 50172, LEDGear™ can work with emergency DC voltage input, such as work with backup or emergency LED drivers (batteries). LEDGear™ works with the backup drivers to regulate the power supplied to the LED fixture the same way normal drivers do, but they operate off of a battery instead of line voltage.

Unknown Flammability Application:
LEDGear™ is suitable for installing on or in furniture which is made from materials with unknown flammability properties (See double M pictogram). Also, it's a temperature-protected driver, with the maximum 110°C surface temperature in the event of a fault at rated ambient temperature (See Inverted triangle pictogram).

Flicker Free By IEE1789:
According to the lighting standard IEEE 1789 2015, the flicker percentage of luminaries is a key figure for measuring the lighting quality. LEDGear™ offers virtually flicker-free dimming (<3.3% flicker percentage) of the connected luminaires, which is in the no-effect region according to the IEEE standard.

LEDGear™, common to all the drivers are application-optimized operating windows for maximum compatibility, high energy savings thanks to low stand-by losses and high efficiency. ■

Use Moso's New LED Driver as "Black-Box" of LED Luminaries

Moso launched their latest X6 LED drivers at the LFI show in the USA. The concept is using the led driver as the "Black-box" of the LED luminaries. X6 LED drivers are developed for professional exterior lighting, including public lighting, industrial lighting, horticulture lighting, etc., with premium quality and advanced functionalities.

Moso strives to simplify luminary design by providing off-line programming and a "black box" function that records any electrical stress excessive temperature data for failure analysis

There are a few innovative designs included in the X6 series, compared with equivalent products in market:

- X6 prices are 15~30% lower than similar designs from other brands in top quality
- Off-line programming outputs in low cost and efficient way
- Black-box" function built-in for easier failure diagnosing
- Timer dimming schedules designed for LED roadway lighting applications, automatically adjust the ratio of dimming hours to adapt to different running hours in summer and winter
- Lumen compensation function designed to maintain same lumen output of LED light fixtures over the life span, achieve 15% more energy saving
- 10 KV surge protection built-in driver to ensure high reliability
- Full range of outputs in all power levels for more flexibility in LED fixture design and tenders

The "black-box" function is an innovative concept in the LED lighting industry. As the heart of the LED fixture, the LED driver bears all risks of luminary failure, thus failure diagnosing is very important. X6 drivers will keep recording the temperatures of critical components and electrical stress data during operation. In case of luminary failure, the user could easily connect the driver dimming wires to a computer to read the temperatures of critical components in a dedicated software, for failure diagnosing and further analysis. ■

LumenRadio - Unique Multi Standard Wireless Lighting Control Solution

LumenRadio presented their new AirGlow product – a multi standard wireless lighting control solution suitable for both indoor and outdoor light control. AirGlow is unique in that it can scale from individual light group control to be used for large scale light control systems with IoT connectivity.

AirGlow® is built on LumenRadio's MiraOS which provides an easy-to-install, ultra-reliable wireless meshed light control

Features:

- Minimal footprint and extensive interfaces for easy integration into luminaire
- Built in advanced autonomous light control functions
- Easy and hassle free commissioning through app
- Stand alone system, no need for cloud service or gateway for operation
- Bluetooth and Mira Mesh multi standard support
- DALI support and other advanced light control inputs/outputs

Wireless technology provider LumenRadio offers patented technologies, a unique operating system, state of the art radio modules and "off-the-shelf" products which provide ultra-reliable mesh connectivity for the most business-critical applications.

LumenRadio's patented CRMX technology has become a de-facto standard within both professional lighting and film lighting. Using the same ultra-reliable connectivity technology, LumenRadio is now entering the Connected Lighting segment, offering fixture manufacturers their new AirGlow product, thereby enabling a quick time to market for reliable wireless connectivity.

AirGlow
At LightFair LumenRadio presented AirGlow – a product platform for both indoor and outdoor light controls that can scale from individual light group control to large scale light control system with IoT connectivity. The product comes packed with powerful and easy-to-use features and is compatible with both Bluetooth and their ultra-reliable Mira Mesh technology.

Due to the small size and versatile interfaces, AirGlow for Indoor usage is ideal for integration both into luminaires as well as integration into standard gang or junction boxes.

AirGlow for outdoor incorporates the LumenRadio's MWA module, which is tailored for outdoor operation. With a line-of-sight range of up to 500 m, AirGlow for outdoor offers performance previously only seen with sub-GHz frequencies.

Enabling Coexistence:
AirGlow enables the world's most resilient wireless mesh connectivity for business-critical applications. The core technology is the Cognitive Coexistence patent that enables your product to coexist along with other wireless technologies, not being interfered and not causing interference.

Plasma Metallization: Lumitronix Utilizes Paper and PET as PCB

In cooperation with its technology partners, the Swabian LED company Lumitronix succeeded in equipping plasma-metallized flexible printed circuit boards with electronic components. This is based on the one-of-a-kind process of plasma metallization. The novel technology from the field of medical engineering turns a plurality of materials into electrically conducting and solderable printed circuit boards that were not suitable for an assembly with electronic components up to this point in time.

Plasma metallization technology may allow for new applications in many disciplines from advertising postcards or posters to illuminated wallpapers and to large-area special applications

Plasma metallization: more than 10 years of research and development
This unique technology is based on more than 10 years of research and development.

This game-changing process has its origins in the field of medicine, where implants or prostheses have been sprayed with bone powder for quite some time already such that these grow together with the body's tissue in an enhanced manner and are not considered as foreign objects and possibly rejected. This know-how was transferred to the field of electronics and, with plasma metallization, a process was created that will be used as the standard from now on.

New and affordable basic materials as printed circuit boards

When compared to the standard material polyizmide, forming the basis for the majority of all flexible printed circuit boards available on the market, the innovative process of plasma metallization results in a plurality of new and affordable basic materials for printed circuit boards.

So far, solderable paper FPCs (FPC = Flexible Printed Circuit) are a novelty and, as a consequence of the new technology, offer a plurality of applications. They are affordable, have no diffusion barrier and are thus suitable for large-scale applications such as wallpapers or advertising spaces.

PET may also serve as a basic material for FPCs. This plastic material is cheaper than polyimide, is characterized by a very good strength, a high resilience, and a low weight. When coated with a thin aluminum layer, which is rendered solderable via plasma metallization, the PET FPCs may be equipped with components. Furthermore, PET is transparent and can therefore be applied to glass surfaces, for instance. Illuminated glass facades of multi-storey buildings, windows, or glass doors are conceivable.

Moreover, aluminum FPCs coated with copper may be used in order to achieve both cost savings and a weight reduction when compared to pure copper FPCs. Thanks to 100 µm thick aluminum, the FPCs are also provided with a high current load capacity and may be used for interior and exterior applications. Since the surface of aluminum is not solderable without further ado, it has not been used in the field of flexible printed circuit boards up to now.

Advantages of plasma metallization

When compared to the standard process utilized for printed FPCs, wherein the basic material printed with non-solderable strip conductors – e.g. made of aluminum – is coated by means of a conductive adhesive with a high silver content, the plasma metallization method is much cheaper. The high silver content used within the framework of the conventional process results in significantly higher financial expenditures and additionally, is complex. Furthermore, it is not that reliable, since the conductivity ultimately depends on temperature and moisture.

Another advantage of plasma metallization is that the high current – more than 10 A, preferably 50 A – and the low voltage – preferably 50 V – used within the framework of the process of irradiation prevent the complete breaking of the molecule chains of the coating material. However, the exclusion of oxygen results in the prevention of a direct oxidation of the coating material within the plasma beam. Therefore, high energies for starting the chemical reaction may be introduced into the coating material, which is why the novel method is particularly suitable for continuous, industrial coating processes with high coating rates.

Series production with Lumitronix

Series production of the flexible printed circuit boards will be performed on a new Lumitronix in-house production line. The new, flexible strip park will be capable of equipping the basic printed circuit boards using the reel-to-reel process.

Applications of the novel technology

Large-area special applications may also be implemented. For instance, metallized paper or PET film equipped with LEDs may be used in order to produce huge illuminated placards or banners for exhibition stands that may simply be disposed of after having been used. A conductive surface may even be applied to functional textiles such as curtains, blinds, soft top cloths and then be equipped individually with LEDs and additional electronic components. The range of applications for the basic materials treated with plasma metallization is truly manifold.

Another option is rapid prototyping, within the framework of which strip conductors made of silver paint are printed to paper using an ink-jet printer, then plasma-metallized, and then equipped. The printing process is significantly easier and less complex when compared to the conventional etching process, with the latter being very complex and also cost-intensive specifically for small numbers. ■

Signify Launches Trulifi High-Speed Commercial LiFi System for Luminaires

The worlds of lighting and telecommunications has converged. Signify, the world leader in lighting, launched a new range of LiFi systems that includes the world's fastest and most reliable LiFi systems commercially available. The range, branded Trulifi, leverages existing and future professional luminaires. Instead of using radio signals (such as WiFi, 4G/5G, Bluetooth, etc.), Trulifi uses light waves to enable highly reliable, secure two-way wireless communications at speeds far above most conventional workplace wireless technologies.

Trulifi uses optical wireless transceiver technology built, or retrofitted, into Philips luminaires. This means customers don't have to rip and replace their existing lighting infrastructure to receive great quality light and wireless connectivity.

Signify describes Trulifi as highly reliable, secure, high-speed wireless communication that leverages existing and future lighting infrastructure, aimed at professional markets, including offices and hospitality

Trulifi overcomes the increasing congestion of the radio spectrum and is perfect for areas where radio frequencies don't work well, or at all, or are not permitted.

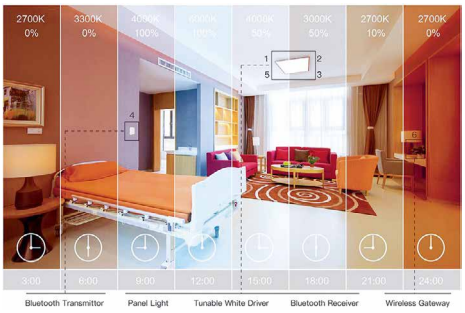
The new range comprises Trulifi-enabled luminaires providing wireless connectivity at speeds up to 150 Megabits per second (Mbps) over large spaces, such as meeting rooms and office floors. There is seamless handover between each Trulifi-enabled luminaire enabling users to roam around. The speed is fast enough to stream simultaneously 30 1080p HDTV movies. A USB-access key, plugged into a laptop, is needed to receive the LiFi signal and acts as an emitter to send data back to the luminaire.

The Trulifi range also includes a fixed point-to-point system, up to 250 Mbps speed, which acts like a wireless cable, ideal for connecting devices. Potential applications include connecting robots or machines in radio frequency (RF) harsh environments like industrial plants, or hospitals where RF communications may not be permitted, or where there's a need to send and receive large data files securely and quickly.

"Trulifi underlines our strategy to unlock the potential of light to address new high-growth markets. Through our global presence, large installed base and industry knowledge, we'll help existing and new customers to leverage their lighting infrastructures to receive reliable, secure, high-speed wireless communication at a very competitive price-point. Wherever there's light, there can now be wireless communication" said Olivia Qiu, Chief Innovation Officer at Signify. ■

I-Star Lighting Circadian System for Automatic, Programmable CCT & Dimming Controls

I-Star Lighting, an innovative global supplier of LED lighting fixtures, LED drivers, and advanced solid-state lighting controls, has developed a lighting system that enables users to program a full range of color temperatures and dimming options to adjust light output throughout the course of the day to provide a healthier, more human-centric lighting environment for interior lights. The I-Star Circadian System natural spectrum lighting combines several different I-Star technology innovations to produce a user-friendly, simplified lighting and control system.



I-Star's integrated wireless Circadian LED lighting system delivers natural spectrum light with user-programmable interface to automatically adjust color temperature and dimming throughout the day

The I-Star Circadian integrated LED lighting system with the following components:

- A series of 2' x 2' panel lighting fixtures that incorporate natural spectrum LEDs with light output that closely matches the spectrum of natural sunlight
- Each light fixture connects wirelessly through an I-Star Bluetooth receiver, forming a mesh network that enables all the fixtures in the system to communicate with each other, as well with a central Bluetooth transmitter module and tunable dimmer control
- I-Star's tunable white LED driver control module provides central dimming and color temperature adjustment for the light fixtures. These modules are available in both linear or rectangular form factors and interface with standard 0 – 10V dimmers
- An I-Star Bluetooth transmitter mounted in a central location interfaces with standard 0-10V dimmer controls and photo sensors to provide a convenient user interface
- Providing central control and user programmability is the I-Star Gateway programmable interface controller, which enables the user to program the overall lighting system to adjust color temperature and light intensity for specific times over the course of the day. The system can also be programmed to respond to the inputs from light sensors in the room
- The I-Star Circadian System mobile app, available for IoS and Android devices, is used to commission the system, as well as to adjust the programming after installation

"This year we are introducing the I-Star Circadian System, featuring natural spectrum LED light fixtures integrated with our innovative wireless lighting controls and a programmable interface module," said Melissa Chen, VP of I-Star Lighting. "The Circadian System lighting enables customers to program the light output of multiple fixtures to automatically adjust over the course of the day, and to wirelessly control their operation from a mobile device." ■

Acclaim Lighting Introduced Numerous New Products at LFI

Acclaim Lighting, a leader in innovative and advanced lighting technology, brought several new products to LFI: Cylinder One HO, an exclusive, high output LED Series for long throw downlight applications; Flex AC Exterior Linear LED Strip for customized applications; Side Emitting Flex Tube SE Spectrum for dynamic exterior, customized color LED lighting applications. – Just to name three of the highlights.

Available in a range of color temperatures and beam angles, Cylinder One HO™ provides very high lumen output from just a six-inch fixture

Cylinder One HO:
Cylinder One HO™ is an exceptional six-inch, high output cylinder fixture delivering up to 12,000 lumens and 99,000 maximum candelas for more than 20-foot ceiling height downlight applications.

Ideal for airports, convention centers, theaters, houses of worship and civic buildings, Cylinder One HO is available in multiple color temperatures (2700K, 3000K, 3500K and 4000K) in several beam angles (15°, 22°, 40° and 70°) with several quick-change reflectors for customer applications. The unit can be installed in several different arrangements including surface mount, ¾-inch NPS pendant mount, aircraft cable mount and wall mount configurations.

Flex AC Exterior Linear LED Strip:
Flex AC™, a low profile, exterior-rated linear LED strip available in multiple colors offering maximum run distances without the need of external power supplies for custom applications. The combination of its high efficacy and low profile makes Flex AC ideal for a wide variety of cove, millwork, signage, and many other exterior and interior applications.

Flex AC is available in 2700 K, 3000 K, 3500 K, 4000 K, 5000 K, red, green, blue and amber with a 160° beam angle. It will provide up to 371 lumens per 1.64 feet, while consuming only 3.8 watts per foot with a CRI greater than 80. Operating at 120 VAC, Flex AC has a 10 – 100 percent dimming capability through ELV, as well as 0-10V and DMX with the use of an optional UDM.

Side Emitting Flex Tube SE Spectrum: Flex Tube SE Spectrum™, a side emitting, outdoor-rated, flexible LED tube with quad-color RGBW LEDs to cover nearly every possible color combination including dedicated whites and pastels for virtually any exterior lighting application.

Controlled with a DMX-512 or DALI for precise dimming and lighting options, Flex Tube SE Spectrum provides a 160° beam angle, while operating off of 24 VDC power. It provides 100 lumens per foot, while consuming only 4.6 watts. Flex Tube SE Spectrum will maintain 70 percent of its lumens for 150,000 hours.

Designed for long-term performance, Flex Tube SE Spectrum features a white UV-stabilized, saltwater-resistant, PVC jacket with silicone top to provide a minimum bend radius of 12 inches and can be cut to a length every 3.28 inches for customized lighting applications. It is IP68-rated and submersible to 3 feet. ■

Soraa VIVID™ Warm Dim Lamps: Achieving New Light Quality Levels

Soraa Inc., the world leader in full spectrum color technology and optical expertise, announced its highly anticipated SORAA VIVID-Warm Dim lamps, designed to equip lighting professionals with a specification-grade dimmable lamp that integrates Soraa Point Source Optics™ and industry-leading color rendering capabilities.

Soraa VIVID-Warm Dim lamps mimic warmer hues found in natural light, while preserving the company's flagship optical and color rendering performance throughout the dimming range

Shifting to pleasing, warmer hues as light intensity decreases, SORAA VIVID-Warm Dim maintains the high color quality that Soraa is known for. Ideal for environments that require warm dimming capability, SORAA VIVID-Warm Dim lamps are suitable for new construction and are a perfect choice for relighting existing installations.

"Adding warm dimming capabilities to our VIVID lamp portfolio showcases the power and versatility of Soraa's signature lighting technology in an elegant form factor suited for every lighting designer's repertoire," said Dr. Kieran Drain, President and COO of Soraa. "These lamps were designed for projects that require beautiful light quality in warmer hues, which is why we made no compromise in the design of these products."

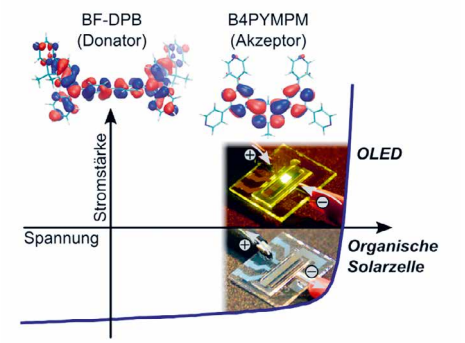
Soraa VIVID-Warm Dim lamps feature new market innovations with three different types of LEDs in a 24-array configuration we call SORAA MOSAIC™ technology to achieve smooth beam edges with the industry's only 24 package design, which is 5 times greater than any other competing warm dim lamp available today. The result is a remarkably consistent light distribution, beautiful beam spread, and high-definition color and white rendering capabilities.

"The design of our warm dim LED package leverages the smallest die available today, allowing us to achieve the unique configuration that SORAA MOSAIC technology brings to our VIVID product portfolio," said Aurelien David, Chief Scientist of Soraa. "Thanks to this, whether the light intensity increases or decreases, SORAA VIVID-Warm Dim lamps' CCT matches the halogen dimming curve from 3000K to 1800K, maintaining perfect color and beam quality throughout the entire dimming range."

Soraa VIVID-Warm Dim MR16 GU5.3 2700 K lamps are available now. Soraa VIVID-Warm Dim MR16 GU5.3 3000K and AR111 are available starting in early Q3 2019. ■

Organic Solar Cells and Light-emitting Diodes United

A team of physicists headed by Prof. Koen Vandewal from Technische Universität Dresden has now succeeded in manufacturing an organic solar cell that simultaneously functions as an efficient OLED. Their findings were recently published in the internationally renowned journal Nature Materials.



Current-voltage characteristic of an organic optoelectronic diode that absorbs ultraviolet and blue photons. Below the open-circuit voltage the diode functions as a solar cell and above as an OLED. The molecular structures show the charge carrier distribution in the organic semiconductors used: BF-DPB (electron donor) and B4PYMPM (electron acceptor). (Visualisation by Dr. Reinhard Scholz and Matteo Cucchi)

A fundamental loss mechanism in semiconductors is the emission of light to maintain the thermodynamic balance between the material and its environment. Precisely this balance between light absorption and light emission in semiconductors is responsible for the fact that "an ideal solar cell is also an ideal light-emitting diode," says Johannes Benduhn, reiterating the basic assumption by the Organic Solar Cells (OSOL) group at the Institute of Applied Physics.

However, organic solar cells are subject to further loss mechanisms which have challenged this assumption until now. Instead of generating light, a large part of charge carriers recombines in the form of heat ("non-radiative"). This leads to a lower voltage and consequently a reduction of the power conversion efficiency, one of the main reasons why organic solar cells are not as efficient as established technologies you can currently find on rooftops. With the newly developed organic solar cells, the OSOL Group was able to keep these voltage losses comparatively low and thus pave the way for higher efficiency and completely new fields of application.

The international research team has succeeded in developing combinations of organic semiconductors based on electron acceptor and electron donor heterojunctions that function as both solar cells and LEDs. The results of this research significantly extend the current understanding of organic semiconductors and combine the physical description of organic solar cells and OLEDs for the first time.

These findings will contribute to the development of more energy-efficient OLEDs in smartphone displays or television screens. The newly developed photovoltaic devices can be used for the efficient conversion of UV and blue photons into electrical power, e.g. in indoor applications for the electrical supply of Internet-of-Things devices or as semi-transparent solar cells in glass facades. ■

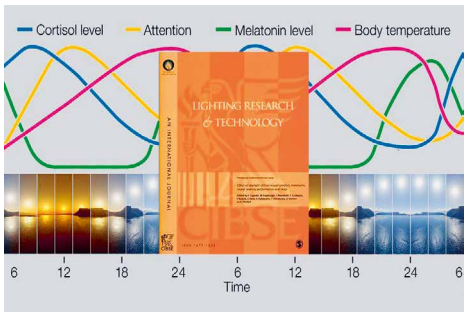
The Organic Solar Cell (OSOL) Group at TU Dresden's Institute of Applied Physics
The OSOL group is part of the Dresden Integrated Center for Applied Physics and Photonic Materials (IAPP) and the Institute of Applied Physics of TU Dresden.
The group was formerly headed by Prof. Koen Vandewal, who is now teaching and conducting research at the University of Hasselt in Belgium.

Original Publication:
Emissive and charge-generating donor–acceptor interfaces for organic optoelectronics with low voltage losses. Nature Materials 2019 (https://doi.org/10.1038/s41563-019-0324-5)

Scientific Study - Positive Effects of Daylight LED on Visual Comfort, Sleep, Melatonin & Performance

There has been an increase in research activity on the relationship between light and human bio-function, including a recent scientific study focusing on the effects of light spectrum on sleep quality, visual comfort, well-being and daytime alertness conducted by Prof. Christian Cajochen and his team at the University of Basel in Switzerland, entitled: "Effect of Daylight LED on Visual Comfort, Melatonin, Mood, Waking Performance, and Sleep."

It is well established that light is one of the strongest control factors for human circadian rhythms, such as the secretion of the sleep promoting hormone melatonin. Thus, optimal lighting condition during daytime are crucial to prevent circadian rhythm disturbances which can lead to sleep disorders and other life-style related diseases. Over the past ten years, there have been related scientific studies in the fields of sleep, chronobiology, physiology, as well as the impact of light quality in elderly care.



In a study investigating the effects of daylight LEDs on humans, several beneficial effects were demonstrated

According to Prof. Cajochen's research, LED light sources with the same measured correlated color temperature (CCT) and intensity, but different spectral output, can have different effects on human behavior and physiology. LED light sources with a spectrum close to natural sunlight produced better visual comfort, more alertness, and happier moods in the morning and evening among the test participants,

compared to those exposed to conventional spectrum LEDs. The research tested subjects' visual comfort, circadian physiology, daytime alertness, mood, cognitive performance, and sleep after being exposed to both conventional LED light, and natural spectrum LED light for 49 hours in a laboratory setting.

Quoting from the paper: "We have evidence that a daylight [natural spectrum] LED solution has beneficial effects on visual comfort, daytime alertness, mood, and sleep intensity in healthy volunteers. Delta EEG activity (0.75–4.5Hz) was significantly higher after daylight-LED than conventional-LED exposure during the post-light exposure night."

By providing the same spectrum as sunlight and in the visible light range, SunLike Series natural spectrum LEDs deliver benefits to human well-being, consistent with the mechanisms of vision that impact both image forming and non-image forming aspects of the eye, as well as the control of circadian rhythms. While the qualities of artificial light have been described primarily with color and intensity thus far, SunLike Series natural spectrum LEDs have introduced light spectrum as another important factor in determining overall light quality.

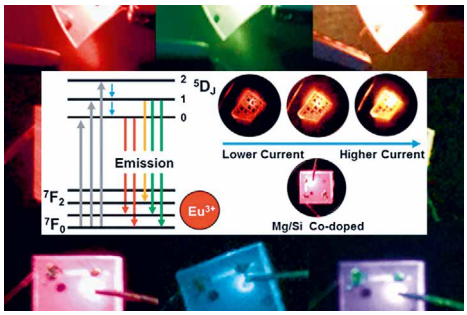
"This research conducted by the University of Basel suggests another important aspect to the evolving direction of artificial light over the past eighty years. In addition to the properties of energy efficiency and long life, we have added the factor of 'human well-being' to modern LED light sources," said Nam Ki-bum, sales executive vice-president of Seoul Semiconductor. "As the world's first mass-produced LED devices to achieve natural sunlight quality, SunLike Series LEDs are advancing lighting technology in this important area as we continue to respond to market needs from our customers' lighting applications." ■

The original article has been published in the Journal of Lighting and Research Technology published on March 24, 2019.

The results of a recent comprehensive sleep study conducted by scientists at the University of Basel proves according to Seoul Semiconductor that its SunLike Series natural spectrum LEDs have been identified as a key light source for promoting human well-being.

Controlling Current, Duty Cycle and Pulses Allows Color Tuning in Monolithic GaN LEDs

A new technique - the result of an international collaboration of scientists from Lehigh University, West Chester University, Osaka University and the University of Amsterdam - could pave the way for monolithic integration for simple color tuning of a light bulb, according to Volkmar Dierolf, Distinguished Professor and Chair of Lehigh's Department of Physics who worked on the project.



The team demonstrated the possibility of color tuning Gallium Nitride (GaN)-based GaN LEDs simply by changing the time sequence at which the operation current is provided to the device

The team demonstrated the possibility of color tuning Gallium Nitride (GaN)-based GaN LEDs simply by changing the time sequence at which the operation current is provided to the device. Light-emitting diodes or LEDs are semiconductor devices that emit light when an electric current is passed through it. Notably, the technique is compatible with current LEDs that are at the core of commercial solid state LED lighting.

The work is described in an article published online in ACS Photonics called "Color-Tunablility in GaN LEDs Based on Atomic Emission Manipulation under Current Injection." The lead author, Brandon Mitchell, is a former graduate student in Dierolf's lab, now an assistant professor in the Department of Physics and Engineering at West Chester University in Pennsylvania.

In today's active LED displays, different colors are produced by three to four individual LEDs that are placed close to each other and create the different fundamental colors needed to produce the full color spectrum.

"We demonstrate that this can be achieved by a single LED." says Dierolf. "We show that is possible to attain red, green and blue emissions originating from just one GaN LED-structure that uses doping with a single type of rare earth ion, Europium (Eu). Using intentional co-doping and energy-transfer engineering, we show that all three primary colors can emit due to emission originating from two different excited states of the same Eu3+ ion (~620 nm and ~545nm) mixed with near band edge emission from GaN centered at ~430nm. The intensity ratios of these transitions can be controlled by choosing the current injection conditions such as injection current density and duty cycle under pulsed current injection."

In other words, the team achieved color-tunability in a single GaN-based LED through the manipulation of the emission properties of an atomic-type dopant.

Mitchell pointed out that "The main idea of this work -- the simultaneous active exploitation of multiple excited states of the same dopant -- is not limited to the GaN:Eu system, but is more general. The presented results could open up a whole new field of tunable emission of colors from a single dopant in semiconductors, which can be reached by simple injection current tuning."

According to Dierolf, this research may benefit those who are looking for more comfortable "warmer" white light from LEDs.

"It could pave the way for monolithic integration for simple color tuning of a light bulb," adds Dierolf. "It would also be beneficial for micro-LED displays, since it allows for higher density of pixels."

The materials used in previous research on color tunable LEDs did not allow for easy integration with current LED technology, he adds. This work is compatible with current GaN-based LEDs that are at the core of commercial solid state LED lighting. ■

Story Source:
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Journal Reference:
Brandon Mitchell, et al., Color-Tunablility in GaN LEDs Based on Atomic Emission Manipulation under Current Injection. ACS Photonics, 2019; DOI: 10.1021/acsphotonics.8b01461

TECHNICAL REGULATORY COMPLIANCE UPDATE

Segment	Product	Standard (Certification)	Region	Technical Regulatory Compliance Informati
Energy Efficiency	Lighting Products	Ordinance No.: 74 / Ordinance No.: 51	Japan	Japan's Ministry of Economy, Trade and Industry (METI) published the new amendment on excluded lighting equipment/bulb types, which comes into force from April 15, 2019 onwards. It mainly covers exclusion of specified energy consumption equipment concerning Article 92.
Safety standard	Lamps for road vehicles	EN 60809:2015/ A3:2019	Europe	This amendment to Lamps for road vehicles - Dimensional, electrical and luminous requirements was published with a DOW 03.05.2022. The amendment 3 now makes references to UNECE resolution R.E.5 and introduces new light source types L1A/6 and L1B/6.
Performance Standards	Lighting Products for road vehicles	EN IEC 60810:2018/ A1:2019	Europe/World	This amendment to Lamps, light sources and LED packages for road vehicles - Performance requirements was published with a DOW 13.05.2022. The amendment 1 now makes reference to UNECE resolution R.E.5 and introduces new light source types L1A/6 and L1B/6.
Performance Standards	High pressure discharge lamps	EN 60662:2012/ A11:2019	Europe	High-pressure sodium vapour lamps - Performance specifications were amended with a DOW of 04.02.2022. With this amendment the standard was harmonised to be compatible with the EU ErP regulations (EC)245/2009 and (EU)1194/2012, and the EU Energy Label regulation (EU)874/2012
Performance Standards	LED modules	Disposition EN 62717:2017/ A2:2019	Europe	The amendment 2 for LED modules for general lighting - Performance requirements was published with a DOW of 28.02.2022. Several updates concerning the terminology, standards for test methods like LM80-15 or CIE S 025/E:2015, and Annex A,C and I were updated

A free training can be arranged for a clear understanding of the upper stated standards.
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Tech-Talks BREGENZ - David Schmidmayr, CEO, SANlight Research GmbH.

David Schmidmayr

David is an expert in LED-lighting with many years of experience in horticulture. Using his in-depth knowledge of photonics and semiconductor technology, he co-founded SANlight (as a company and research institute), with the purpose of developing and manufacturing LED illumination systems for commercial greenhouses, special applications and household use. SANlight won the "Born Global Champion" award in 2016.

Horticulture lighting has become an increasingly important topic in the LED lighting industry business. A small, highly innovative company is located about 50 km from the LED professional offices, which made it easy for the founder to come to Bregenz for an interview. David Schmidmayr, CEO of SANlight Research GmbH, talks about SANlight's beginnings and background and the restructuring that took place and new joint ventures that were established. He was especially excited to talk about the requirements of plants and the users of horticulture lighting, the technology and SANlight's approach to this lighting domain.

LED professional: Thank you for coming to talk to us. I think the first thing we would like to hear about is your company. Can you give us some information?

David Schmidmayr: The company, SANlight, started as a university project. My colleague, Martin Anker and I went to the same class and we came up with the idea of doing a project concerning light and plants. Because of our backgrounds, we started a project, where we made some prototypes and did some feasibility studies. Once we had the first prototypes and saw how well it was working we decided to take the next step and begin proper product development. Our first module – the M30 – was actually born before the company was founded in 2012. We started off in the small markets– mainly in the hobby market – with small LED modules.

At that time the LED technology in that market didn't have a good reputation. Greenhouse growers were of the negative opinion that LEDs wouldn't work with plants, mostly because there were many products on the market that really didn't work! A lot of companies were only selling the three letters instead of the technology behind it.

LED professional: Coming back to the founding of the company: You said you were studying at university at the time, but as far as I know your studies didn't have much to do with plants. Why did you start a project that had to do with lighting for plants?

David Schmidmayr: Oh, it was like this: Martin and I were studying Mechatronics at the University of Applied Sciences here in Vorarlberg, but it turned out that we both have a "Green Thumb". Martin has a big garden at home where he grows a lot of his own food and I love working with Bonsai trees. I guess you could say that we both have a special relationship with plants.

LED professional: So you combined your personal interests with your studies.

David Schmidmayr: Exactly. My first step towards the area of photonics was when I did my bachelor's thesis for a laser company. I was developing a sensor system for femto-second-lasers. Laser technology had always fascinated me and taking that first step in the direction of photonics, I got hooked. And then I had the chance to work in the research center for micro technology during my Master's study and also a few years later. I worked in a research project where I was involved in novel color conversion materials for white light LEDs and I learned a lot. In the end it was a perfect combination of what we liked from a technical point of view and what we liked doing in our spare time. Generally, we thought that the combination of photonics technology with the botanical field would be very, very interesting.

LED professional: How long ago did you start the project and how big is the company today?

David Schmidmayr: I think we started the project about ten years ago. We have had an astounding growth rate. But this has also brought some challenges with it. When we first started there was no hierarchy. We were

David Schmidmayr and Martin Anken shared the same passion for plants and lighting during their studies at the University of Applied Sciences in Dornbirn. The founding of their company, SANlight, was the result of a project they carried out there

just colleagues, working together. Then, as we hired more and more employees, things got more complicated. The product range grew and the overhead grew, which led to us having to make a lot of changes last year. We introduced processes and structures and changed the entire structure of the company. At the beginning of last year it was SANlight GmbH but then we decided to extract the research part. Research was a very, very important part of the company right from the beginning. We used to go down to the cellar with our prototypes to test how the plants grow with 100% artificial light. The goal was for the plants to grow naturally, producing flowers and fruits. We wanted the plants to grow the same as they would have under natural sunlight. So right from the beginning we had our own laboratory – our own research department – where we could investigate the interaction of light on the plants. We didn't only research how we should develop our products, but we were also improving our knowledge of the biology of the plants. And that was a very important factor. Light is only one aspect. You can also make a lot of mistakes when it comes to illuminating plants. We started off in a room in the cellar that was 16 m^2 in the house that we lived in, and we had our first employee there. Today our office, production and R&D is in Bludenz, all on 1,000 m^2 in a 140-year-old textile factory. It's an interesting and inspiring location!

LED professional: I understand that you work together with Lumitech, is that correct?

David Schmidmayr: Yes, that's right. That was one of the major changes we made last year. We founded a second company called SANlight Research and made a joint venture with Lumitech called SANlight Solution. In this joint venture we focus on the B2B market. This is especially for professional growers and also industrial applications – wherever there is an interaction between plants and light.

LED professional: What do you mean by an industrial application that interacts with plants?

David Schmidmayr: For example, the illumination of algae bioreactors, where you have industrial sized photo-bio-reactors that are typically powered by natural sunlight. But depending on the type of algae you grow and what the algae is used for, it can make absolute sense to use artificial light to increase the yield. This is a very hot topic at the moment, like if it is used as a food supplement or cosmetics or pharmaceutical applications.

Lumitech approached us in late 2017 and asked if we were interested in a joint venture. We looked very closely at them and found that they were the perfect partner for what we want to do. At that time we were also in a phase of strong growth and we needed to establish processes and structures in our company - so it wasn't just about founding a new company and increasing our revenue but it was also about learning from a company structure. Lumitech has been in the LED business for more than 20 years and I think we can learn a lot from them.

LED professional: What are the roles of SANlight and Lumitech in this co-operation?

David Schmidmayr: The competencies of SANlight are in the field of the interaction of light with plants. We know what plants want, how they work, what the greenhouse growers' problems are, what they need and how we can help them. Lumitech has a solid understanding of phosphor conversion. And they have also established structures in their company, which is very important for us because we want to learn from them and implement the structures in our own companies. Also, if we look at light control systems, Lumitech also has a lot of knowledge in that area. And of course using synergy effects that we can combine our sales volumes to decrease production costs.

LED professional: Do you work together with universities to gain the biological information you need?

David Schmidmayr: Yes. We have a rapidly growing network where we work together with biologists and phytochemists. We have a research cooperation, for example, with the Austrian Agency for Food Security in Vienna – AGES, as well as the MCI in Innsbruck and many more – also outside of Austria. These are very interesting cooperations because there are so many open questions and we can learn from each other.

So you also have to be careful to stay on track – not to lose yourself in details. In the end we have to focus on the market: What do the growers actually need? One of our first luminaire prototypes had a controller implemented in it and we could mimic the changes in natural daylight using a lot of different LED channels that were independently controlled. For us, as scientists and technicians, it was really great. We introduced a grower to the technology – we gave him the lamp to use in his green house – but the result was that there was no result! At first it sounds impressive when you tell him that if he changes the ratio of blue and red he can get his plants to be smaller and compacter. And in the end, the yields were worse than they would have been without artificial light. And that was when we realized that the market needs something that is plug and play. All they have to do is put it in their greenhouse and have good results.

Of course we had our special luminaries that we used for our research, but we know what we are doing when we change the light colors and the intensities. These fixtures make it easy to find out what different types of plants prefer. And then we can develop products for applications that are actually needed on the market.

LED professional: I have been in the lighting business for many years now, and for many years nobody even talked about horticulture lighting. I have to admit that when I first made contact with you I thought that it was just a "fancy niche" that you were working in and now it's all over the place. How did it get to be so important and so interesting? Was it because of the new possibilities brought about by the LED?

David Schmidmayr: Yes. I remember the point in time that we started our project very well. We were, in fact, at the LpS in 2011, going around and talking to the exhibitors. The impression we got then was that they were just humoring us. But this has changed dramatically over the past few years. I think it's hype for many reasons: First of all, because the technology has reached a level where you can generate wavelengths with intensities that are needed in the horticulture business, but also because there is a movement going on in society. More and more of the younger generations are concerned about where their food comes from and how it is produced. The worry about how many kilometers it was transported and which pesticides were used. With LED technology you can produce your micro-greens, your lettuces, your baby leafs, etcetera, in your own living room! There you would have complete control. You use the water from your tap so you know it's clean and you use the substrate that you bought

Many companies propagate multi-channel solutions, mainly with adjustable red and blue LEDs for horticulture, leading to the pinkish-purple tint as shown in this image. SANlight's own research showed no convincing benefits over a well balanced. red-blue enriched, white spectrum for most applications. In many cases, simplicity and cost effectiveness are most relevant for the customer

from a local gardener and you can grow your own organic food. And this movement has a big influence on the market.

LED professional: But I don't think that would be a reason for big companies to enter in this field. I think there must be a big economic interest.

David Schmidmayr: Yes. It's a huge market. The global population is continually growing and food has to be generated. There are some studies that predict that by around 2050 an area the size of Europe would be needed to feed the world population if we go on using the same agricultural techniques that we use today. I'm not sure how accurate this data is, but I am aware of the problem and I think, with LED technology and horticultural lighting based on LED technology we will be able to help solve this problem.

LED professional: This is interesting because I recently read about some old Underground facilities in London that are completely dark and are now being used to grow lettuce and other things with this technology.

David Schmidmayr: There is a trend called urban farming that is becoming popular. It's similar to what you mentioned about using the bomb shelters in London. In urban farming they try to produce the food where it is needed. This makes sense if we look at big cities like Vienna or Paris, for example.
You often have abandoned buildings in the industrial areas around the cities. With modern technology you can build vertical farms in them. You can use the existing infrastructure like transportation, buildings, electricity and sewage installations. Then you can produce things like micro-greens or baby leafs, vegetables and foods that don't need that much energy to grow. They grow very fast and you have very short transport routes to the consumer.

LED professional: If you look at plant growth, it can be optimized for different types of properties like flavor, vitamins, organic, trace minerals, etcetera. In order to reach these targets, do you need different spectral distribution or can you use the same spectral distribution for all of these things?

David Schmidmayr: You can go both ways. A simple way to explain it is if we look at how many million years the plants took to adapt to natural sunlight. Of course it varies slightly during the day but overall, it's a steady spectrum.
Our customers and also in our research, we focus on a spectrum that works for about ninety-five percent of the applications.
This makes sense because we can tell the customer to use that specific light source – it's simple to use, plug and play and you have maximum flexibility. So if you decide to grow tomatoes today and cucumbers tomorrow, it doesn't matter. You just have to switch your plants and leave the light installation there.

LED professional: Can it adapt to the spectrum without changing the program?

David Schmidmayr: Yes. Of course, if you go into detail, there is always potential for optimization.
But generally you have to look closely at the application and the whole business model of the growers - how and when they sell

their products; how the prices fluctuate during the year and then you can decide if it makes sense to do the optimizations. But you really have to look at the application in detail.

LED professional: Spectral distribution is one side; the other side is the time distribution. Natural light is "on" for around sixteen hours and "off" for eight. Can you accelerate plant growth if you make the dark phase shorter?

David Schmidmayr: In general, yes, but not for all plants. If you look at plants like baby leafs or micro greens, you can illuminate them for eighteen hours, it's no problem for them. During certain periods of some plants, during the early stages, you can even illuminate them for twenty-four hours, but it's stressful for them. During the dark period, their metabolism changes and they need that change to function well. They would get sick if they didn't have the resting period – just like humans.

There are very interesting things going on in the field of research regarding the dark period. For example, there are different red light receptors in the plant that are responsible for the circadian clock inside the plant. If you know which wavelengths react or influence the composition of the "hormones" in the plant you can shorten the time the plant needs to realize that it's in the dark phase. By doing this, you can, in theory, reshape the twenty-four hour light cycle: You could give your plant light for eighteen hours, then you give the plant only three hours night with a special composition. You get more biomass generated within a certain time span. This is being investigated at the moment.

LED professional: Is it being implemented already?

David Schmidmayr: No, we are still doing research on it. I think it will take a while before growers can benefit from it. And it would only work in a completely dark environment.

Robust, simple, efficient and cost effective - these were the functional specifications for the design of the SANlight module

LED professional: In some green houses, they use artificial light when it's cloudy outside. How would these two different applications split up in the agriculture industry?

David Schmidmayr: If we look at solely artificial lighting applications, the main market is the vertical farming and the production of medicinal plants because you need a controlled environment there.

In the traditional greenhouse market, it's different. There are established structures and methods and it's a little more complicated. You have to introduce the grower to LED technology. My approach is to give that grower the chance to try LED technology. They can run trials together with me and I would give him a lot of information so that he gets the best out of the technology. That way he can see how he can benefit from it. Once they see the benefits, almost all of them are convinced.

LED professional: We know from the biology of the plants that light is one aspect, nutrition is another aspect, water is another aspect, and then there are temperature, humidity and so on. How far is it going in the control system? How well are all these factors controlled in one single controls system?

David Schmidmayr: That's a very important topic. At the moment, when we realize a project, we have a network of partners that are specialists in the different fields. But what I see on the market is more and more companies offering turnkey solutions for the control systems for the environments where you want to grow plants with certain standards.

When we are working with growers and our LEDs, it's not just that they have to swap their luminaires but we go through all the details with them because if you compare an HPS lamp to an LED, a major difference is that you're missing infrared radiation with the LED. For plant growth this means that if you're radiating your plant with heat radiation you will have more transpiration from the plant and you will use more water. This means that your concentration of nutrients in your irrigation water will be a little bit lower to get a certain amount of nutrients within a certain time span, into the plant. If you run this same nutrient density with an LED system, where there isn't as much water exchange in the plant, you need to increase the concentration of nutrients. And then you have the de-coupling of light and climate with LED technology because with HPS, you turn them on and you also heat your greenhouse. The leaves get warm from the heat radiation, which drives photosynthesis but it can also be a negative effect. It can also cause stress. By using LED technology we can separate climate and light and that makes the whole process much more controllable.

Doubtless, one of the biggest benefits of horticulture lighting is when it comes to growing seedlings, micro-greens, lettuces, and baby leafs. Artificial illumination is also beneficial for growing greens and algea for medical applications

So it's very important to not only have the lighting knowledge, but also the biological knowledge to really get the best out of an LED system.

LED professional: You mentioned different markets like the industrial market for algae growing, you mentioned vertical farming and you mentioned the, more or less, private user for horticulture lighting. Are you trying to be in all of these markets? Do you have different products for different markets? How do you access the different markets?

David Schmidmayr: Basically, our product line covers about 80% of the markets that you mentioned. It is also our goal to have products that suit all the markets. If we look at the industrial applications, a lot of them are customized.

In the B2C market, if we're looking at home applications, we distribute our products through distribution partners. In the professional market we target the customers directly because it's very complex and you need a very high level of consulting in this area. It's not like you can just choose a luminaire from a catalogue and replace your HPS lamp and everything would be the same except that you would use less energy. It wouldn't give you all the benefits of LED technology.

With LEDs you have the huge advantage of the more precise steering of the light. When you go to the grower you see how the tables are distributed and you immediately start to figure out how to get the most light into the cultivation area.

LED professional: So you have mainly the same products for all the markets, you have two different types of business – the project driven business and the commercial – let's say – off the shelf business.

David Schmidmayr: Yes. And of course for the professional market we have certain differences in the products because we need higher ingress protection classes, maybe higher lifetime and other plugs that are compatible with installations that are already in the green house. So there are slight variations but the main part of the luminaire is the same for most markets.

LED professional: We also discussed the subject of lighting control: Do you also have controllers or does everyone who uses your system just switch it on and off with a simple clock?

David Schmidmayr: We do have controllers but they are mainly used for research. It's a matter of costs and at the moment it makes sense only to use the on/off switch in the green house. We will add dimmable luminaires this year but we can realize very simple control systems with on/off luminaires by using photo sensors. If the weather turns bad and the illumination in the greenhouse drops, the LEDs are turned on. Of course, for further optimization, dimming makes sense. But you also have to consider that it is an expensive installation if the dimming is always low. If we install luminaires we want to have them running on 100% for as long as possible in order to get the full benefit of the investment.

LED professional: Do you believe that the horticulture market will keep to grow rapidly? What type of technological developments do you see coming?

David Schmidmayr: I think it will be a strong growing market. If we look at developments on the technological side, we can see that there is still potential for increasing the efficiency of LEDs, especially if we look at certain wavelengths that could be interesting for horticultural applications. So I see an increase in

efficiency coming up in the future, a cost down in the products, which will also drive the market, as well as the development of new wavelengths that are available on the market – for example, UV with certain wavelengths and certain intensities. Because we know the direction that technology is taking, we will be prepared for future applications by focusing on research. And I see a huge potential there, especially UV applications and medicinal plants because with UV we can put stress on a plant. The plant may react by increasing certain contents that can be used in a drug. Of course it would be very interesting for pharmaceutical companies.

LED professional: You said something about the development of new LED colors and the efficiency of LEDs. There are different options you can choose to do that, like the LED itself being red or magenta, and the other way would be with phosphors. You are a partner with Lumitech, who specializes in phosphors. So do your systems rely more on phosphor based LEDs?

David Schmidmayr: At the moment it's a combination of both. The end result should be a luminaire with a maximum light output for a minimum energy input and a maximum of biological quantum efficiency. So if we are looking at phosphor converted LEDs, we need them to cover broad spectral areas that are important for plants, especially in the green regions where green light emitting LEDs aren't that efficient. But if we want to transform a blue photon into red light, we have a huge energy difference, which means huge losses. So for the red and blue colors we use direct generated light from the LEDs and for the part in between we use the phosphor converted LEDs. We follow the developments very closely. We are also in close contact with LED manufacturers looking for solutions that can be implemented in horticulture lighting. Also, if we're talking about broad emission spectrum – we see a lot of this purple light on the market – which mainly focuses on the absorption peaks of the chlorophylls, which, of course makes sense, but if you have ever been to a farm where this light is applied to the plants, you immediately see the negative effects. The plants grow, but they generate a lot of chlorophyll but depending on the plant that you're growing – this is not what you want. A huge drawback is also that it's impossible for humans to work in this purple light. The plants actually look black or grey and you can't see if they are sick or have a fungus or pests – and that makes it very critical. So finding the sweet spot between the perfect light for the plants and the perfect light for the human eyes is also our job.

LED professional: A very complex and interesting topic! It seems that there is still a lot of research to do.

David Schmidmayr: Yes, that's right – and I'd like to point out that we have our own research network but we also provide research to other companies like LED manufacturers and we are always open for cooperations.

LED professional: Thank you very much. It was very interesting. ■

Lighting System Based on Visible Light Communication

Throughout the last decade, fostered by the properties of solid-state lighting devices, several new approaches and trends have been evolving quickly. One of these new technologies is visible light communication (VLC). LEDs allow for a quick, invisible modulation of the light in a digital pattern that can be used to transfer information. This can be used for different applications and tasks. One of these applications is a communication to coordinate luminaires and their actions. In partnership with HSi Elektronik AG, the authors, René Grabher and Guido Piai from the Institute for Electronic, Sensors and Actuators (ESA) of the Interstate University of Applied Sciences NTB, developed an innovative system in the context of a project sponsored by the Swiss Innovation Promotion Agency (Innosuisse).

New capabilities coming with the introduction of LEDs to the lighting domain also open new applications and beneficial, smart solutions that can ease commissioning, and further reduce energy consumption. This paper presents such an approach; a lighting system based on visible light communication (VLC). A group of luminaires should be able to communicate through the power LEDs (sender), already present on the luminaire, and an additional photo diode (receiver). The communication has to be cheap and reliable. Objective of the system is the coordination of the luminaires, not the transmission of digital information. The luminaires implement a specific type of swarm behavior, coordinating themselves through VLC. The basic idea, the concept, the realization and a proof of concept is demonstrated and discussed.

Introduction

In the field of professional lighting and building automation, there is the need for monitoring, control and coordination of groups of luminaires, which illuminate offices, corridors, stairs, garages, etc. Electronic control gears (ECGs), used to power the light sources, offer several international supported wired and wireless interfaces: analogue 1-10 V interface, DALI (Digital Addressable Lighting Interface), DMX (Digital Multiplex), KNX (Konnex-Bus), PWM interface, Bluetooth, ZigBee to mention some of the most used. In a first category of systems, the ECGs are connected to a central unit or gateway through a wired or wireless connection and need to be addressed in order to be controlled. The process of addressing the luminaires is time consuming and costly, due to the need of establishing a correspondence between the specific spatial position of the luminaire in the building and its digital address. Other systems use a wired or wireless connection between ECGs but avoid the use of a central unit, achieving a distributed system. Each ECG integrates, in this case, a control unit, and a swarm behavior can be programmed in the software of the ECGs [1]. Also, in this case, the addressing of the luminaires is necessary, although the process is easier and can be directly performed at the luminaire. In both cases, the luminaires coordinate themselves using presence detectors and photo diodes as input sensors, in order to detect people and moving objects and measure the intensity of ambient light. The integration of the wired or wireless communication includes implementation, installation and approvals costs. In order to overcome these constraints, HSi Elektronik and the Institute ESA discussed the possibility of developing a 1PWM: Pulse Width Modulation low cost system using VLC to coordinate the luminaires. A presence detector should be integrated in each luminaire, in order to monitor a specific space area. When a luminaire detects movement of people or objects, it should use VLC to instruct the surrounding luminaires to generate some light themselves. A fading halo should arise around the person or object to be illuminated. In this way, efficient (low power) and effective lighting is achieved for the user. The lighting system should be reliable, not be influenced by ambient light and be possibly ruggedized against disturbances. Such a system would only need luminaires connected to

the power grid: no additional costs for wiring or for addressing would be necessary. In addition, such a system could also address the wish for non-proliferation of wireless devices present in certain sectors (e.g., hospitals) [2].

Basic Principle

Each luminaire has three sensors and one actuator (Figures 1&2). The sensors are a PIR (Pyroelectric Infrared detector) presence detector and two photo diodes. The actuator comprises the power LEDs of the luminaire, driven as one body. A microcontroller is the central processing unit of the luminaire. A modulator and a demodulator circuit link respectively the power LED array and the photo diodes to the microcontroller.

An optical air path links two different luminaires. The incoming light is the superimposition of several components.

Superimposition of components:

- Direct light from another luminaire, through a direct line of sight
- Indirect light from another luminaire, through reflections of several kinds
- Self-generated light, through reflections of several kinds
- Extraneous light generated by other light sources
- Ambient light

The PIR sensor of a luminaire monitors a limited spatial area. When it detects moving objects or persons, the luminaire switches on and generates light with a programmed dimming level. Simultaneously the luminaire radiates a VLC command. The surrounding luminaires recognize the command and measure the intensity of the received signal, estimating in this way their own distance to the sending luminaire.

The surrounding luminaires choose a dimming level that decreases with increasing distance. Hence, a fading halo appears around the moving object or person (Figure 3). In this way, efficient (low power) and effective lighting is achieved for the user. If the PIR sensors detect no more movement, the system fades the light out after a defined time.

The system has to be robust against different levels of ambient light, working well during the day and at night. External light sources such as discharge lamps, fluorescent lamps, LED luminaires, even PWM dimmed, should not disturb the system. Additionally, the system has to work in several kinds of ambient, such as offices, stairs and corridors, field paths, garages and be robust against different kinds of surfaces: dark, bright, reflective, opal, shimmering, just to name a few.

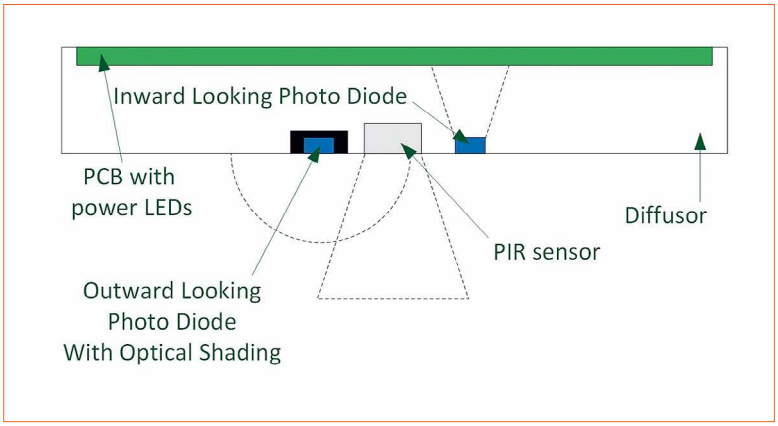


Figure 1:
Cross section of the luminaire

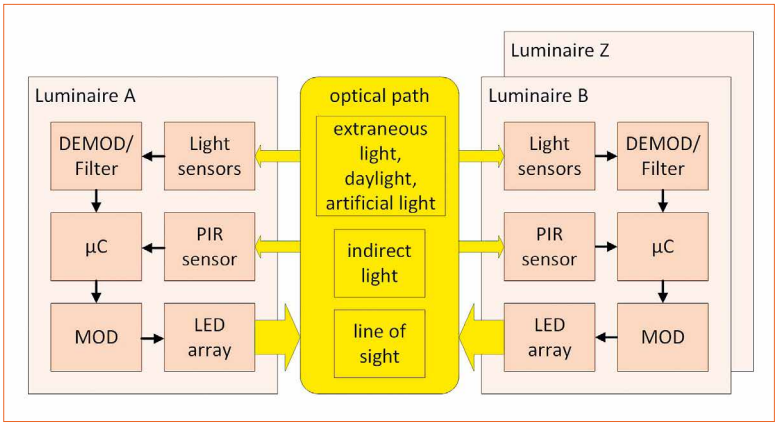


Figure 2:
Block diagram of the lighting system

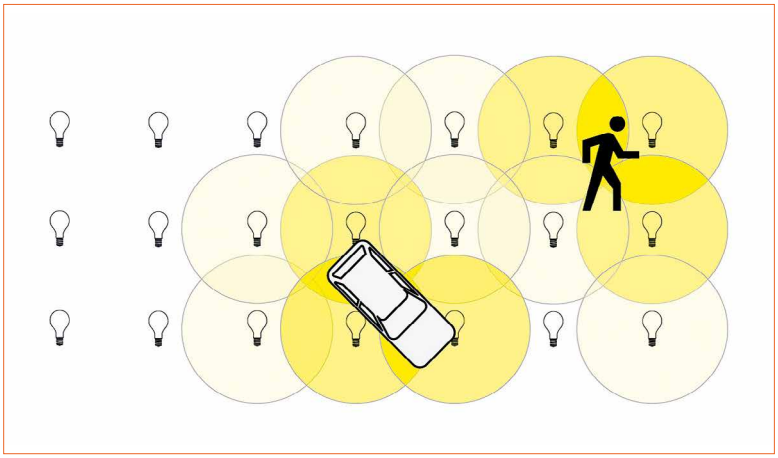


Figure 3:
Overview of a field of luminaires

Sender

Block diagram

The sender consists of the array of power LEDs, which are primarily the light source of the luminaire. A first power supply, connected to the AC power network, generates a constant output voltage (for example 24 or 48V DC). A second stage, configured as a step-down

Figure 4:
Block diagram of the sender

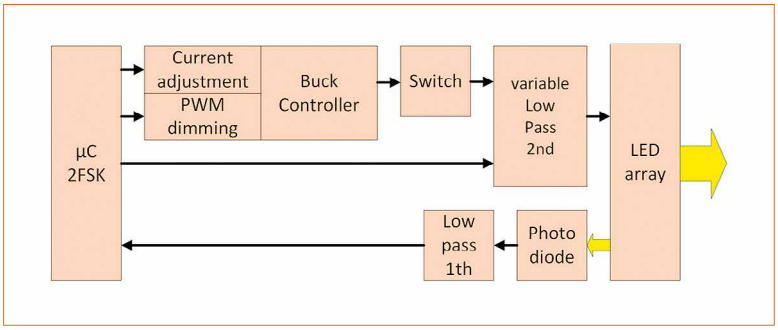
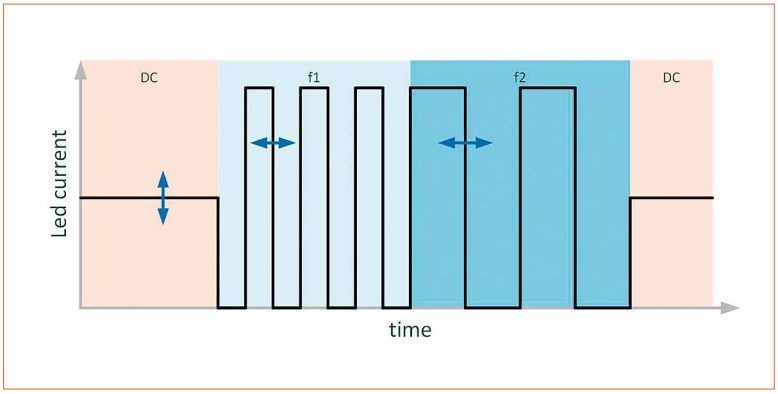


Figure 5:
Overview of the communication scheme



converter, regulates the current sourcing the LEDs (Figure 4). The microcontroller sets the target current of the step-down converter according to the desired dimming level.

During normal operation (lighting), which is also the communication receiving mode, the output current of the step-down converter and its regulation circuit are compelled to have a low bandwidth, in order to achieve very good current regulation and therefore a very stable light emission, so as not to disturb or saturate the sensible receiver circuits. During transmission mode, the output current of the stepdown converter and its regulation circuit are compelled to have a wide bandwidth, in order to react rapidly and be able to generate a sharp square wave signal with a frequency in the range of 10 to 11 kHz.
A variable filter, controlled by the microcontroller, achieves the change in the bandwidth of the step-down converter. The stable light emission during normal operation allows achieving longer communication distances. The luminaire is able to send messages through a Frequency Shift Keying (FSK) modulation scheme. The sender is able to generate two distinct frequencies to code respectively logic 1 and logic 0 (Figure 5).

Current control versus PWM

The current control dimming was preferred to PWM dimming, because a cheap 8-bit microcontroller has no high resolution PWM modules, needed to realize smooth dimming at very low brightness levels and at relatively high PWM frequencies (25 to 50 kHz). Additionally, if the frequency of the PWM is not precise, adjacent luminaires can potentially generate disturbing stroboscopic effects [3]. Finally, the use of current control allows the development of an easier and more efficient receiver, which does not have to filter the eventual PWM frequency used in the lighting mode.

Self-calibration of the luminaire

A challenge of the switching between lighting mode with constant current and transmission mode with PWM is to maintain constant brightness, despite dimming level: the observer should not perceive any change in luminous intensity. PWM allows a linear regulation of the brightness, through the ratio between on time and the period of the square wave. Current control in contrast allows linear regulation of the current but is affected by the nonlinear relation between current and the luminous flux of the LEDs [4]. The overall tolerances of the components also affect the brightness levels achievable through current control and PWM. First experiments showed that the calculation of the duty cycle of PWM corresponding to a specific current level did not work well enough: brightness steps were still perceivable when the luminaire switched from lighting mode to transmission mode, especially at low brightness levels. In order to solve the problem, an additional photo diode was used, which directly senses only the self-generated LED light (Figure 1). At startup, the luminaire now generates three short brightness sweeps (25 steps). During the first sweep, brightness is changed through current control. During the second sweep, brightness is changed through duty cycle control of a PWM with constant amplitude, run with the first FSK frequency (10 kHz). The third sweep equals, in principle, the second, but is run with the second FSK frequency (11 kHz). The internal photo diode measures the different 75 brightness levels and generates a calibration look up table. States in between are interpolated. In this way, an effective compensation can be achieved and the switching between lighting mode with constant current and transmission mode with PWM is no longer visible. A continuous fine tuning of the calibration of the brightness levels during the switching between lighting mode and transmission mode could be additionally implemented, although not pursued in this project.

Sending messages

When the PIR sensor detects movements, the sender switches to transmission mode and radiates messages, which consist of a synchronization header and of a command byte (Figure 6).

Three commands are possible:
- Movement detected
- Broadcast on
- Broadcast off

Further details will be explained in section IV dedicated to the receiver and in section V dedicated to swarm behavior.

Receiver

Block diagram

The receiver sensor is an outward-directed photo diode, which is optically shaded from direct self-generated light (Figures 1&7). A first high pass filter decouples the slow changing ambient light, avoids saturation and increases sensitivity of the following stages. A high gain transimpedance amplifier (TIA) converts the photocurrent into a voltage level. A band pass filter then selects the frequency band of the FSK modulation. After an additional amplifier combined with a limiter, the signal feeds a phase locked loop (PLL), which is able to snap in at both frequencies of the FSK modulation [5]. The output of the loop filter of the PLL, which is a voltage directly proportional to the frequency of the detected signal, feeds an additional low pass filter, which in turn feeds through a Schmitt trigger a digital input of the microcontroller. A timer module recognizes the header of the message and a UART (Universal Asynchronous Receiver Transmitter) module reads the command byte coded through the FSK. The filtered signal of the TIA (Figure 7) also feeds an envelope detector, which estimates the maximum value of the FSK modulation signals. The microcontroller samples this signal through an ADC (Analog to Digital Converter) and achieves in this way a measure of the intensity of the received signal (RSSI - Received Signal Strength Indicator). The RSSI is a good measure of the distance of the sending luminaire and can be used as additional parameter to determine how the receiving luminaires should react.

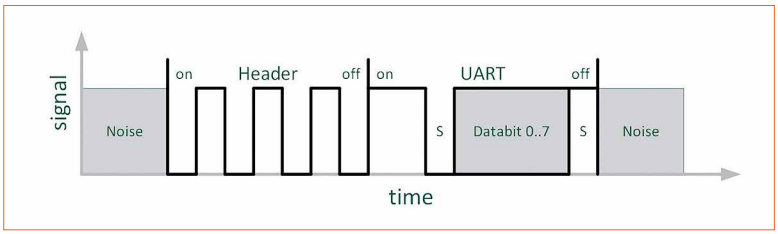


Figure 6: Communication protocol

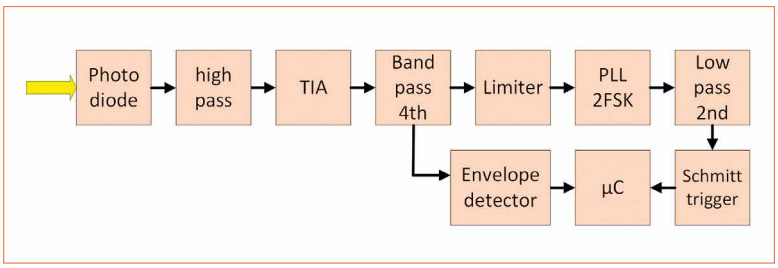


Figure 7: Block diagram of the receiver

Receiving messages

A timer module of the microcontroller continuously monitors the output signal of the PLL in order to detect the communication header, consisting of three low and high sequences (Figure 6). After the detection of the header, the software switches a UART module on, which decodes the command byte, then saved in the memory. The header helps the PLL synchronizing to the FSK frequencies. The postponed activation of the UART module allows for noise rejection.
This procedure is effective and necessary, because the PLLs unfortunately tunes into spurious noise frequencies during idle phases.

Swarm Behavior

The luminaire has two pieces of information at disposal in order to establish its own reactions: the received command and the RSSI. According to these two parameters, a swarm behavior can be defined.

Commands and swarm behavior

We defined three commands:
- Movement detected (MD)
- Broadcast on (BO)
- Broadcast off (BF)

If a luminaire detects movements through its PIR sensor, it switches on, generates light and radiates one MD command. A surrounding luminaire receives the command and measures the RSSI.
The receiving luminaire switches on and adjusts its dimming level according to the RSSI. It does not forward any command. In this way, a fading halo is generated around the moving person or object. After a programmable period, if the PIR sensor detects no movement, all luminaires fade out, starting from their actual dimming level. Therefore, the system switches off gently. If the PIR sensor continuously detects movements, it generates signals in specific time intervals. The detecting luminaire then radiates periodical MD commands, which keep the system switched on. MD commands are radiated only once per PIR sensor detection. Proper time constants choice stabilizes the behaviour of the system. We implemented also BO and BF commands, in order to allow the switch-on or switch-off of all luminaires as a group. This can be useful in case of inspection or of cleaning. In this case, the receiving luminaire forwards the BO or BF command, so that all luminaires can be reached. As a result, the microcontroller ignores in this case the RSSI. A user can generate BO and BF commands through the pushing of buttons on the functional models. In the final product, a smartphone or a special torchlight could generate these commands, because buttons on the luminaire would be impossible to reach. Alternative luminaire behaviors could be implemented, although we intended to keep the first system as easy as possible.

Figure 8:
Example of an indoor test of the luminaires

Figure 9:
Example of outdoor test of the luminaires

Figure 10:
Example of test setup

Communication conflicts

A conflict could arise, if several luminaires try to radiate messages at the same time. We encountered no special problem in these cases. PIR sensors are focused on independent spatial zones and therefore generate signals at uncorrelated, random times. In the event that two messages really overlap, the PLL circuit matches the stronger signal.

Experimental Results

After calculations, simulations and laboratory tests, we developed a first functional model. We produced ten luminaires, in order to test the system.

Ambient light

The AC coupling of the photo diode proved to be very effective. The receiver is able to work properly in all cases.

Test cases:

- Darkness (0 Lux)
- Ambient light generated by fluorescent lamps (300-600 Lux)
- Natural daylight combined with light generated by fluorescent lamps (500-1000 Lux)
- Bright daylight of a light afternoon (2000 Lux)

We made no tests in the presence of direct sunlight, because we considered this case of no real practical relevance.

Operating distance

The luminaires were tested, in order to measure their capability to communicate at distance.
Ten luminaires were distributed over a distance of 30m. (Figure 10). The RSSI and the effectiveness of the communication were measured.

We achieved reliable communication at least up to 20 meters, dependent on the characteristics of the environment and on the dimming level (Figure 11). We have tested the lighting system in the following environments: dark corridors, light corridors, stairwells,

outdoor areas with several types of pavement. Communication was stable (10 positive results from 10 tests). Superimposed fluorescent lamps were no problem.

Immunity to interference

Although fluorescent and incandescent lamps do not disturb the system, extraneous LED luminaires, possibly dimmed through PWM, could be a potential threat. Therefore, we decided to test the communication in the presence of specifically generated interference. The test setup is depicted in Figure 12: two VLC luminaires are flanked by a third luminaire, programmed to generate light through PWM dimming with 50% duty cycle and a variable frequency, in order to try to disturb the receiver circuits. The distance between luminaires was approx. 3 m.

Figure 13 shows the measurements' results. The error rate is almost negligible for frequencies, which are clearly lower or higher than the two frequencies used by the FSK. When the PWM frequency of the disturbing luminaire nears the band from 10 to 11 kHz (used by the FSK), the communication system can be disturbed. This is the case especially of low or high dimming levels, in which the duty cycle of the communication square pulses is lower than 20% or higher than 80%. Between 20% and 40%, sensitivity to disturbances is still present. In the field between 40% and 80%, the lighting system can function well, despite the extraneous PWM light source.

The presence of interfering light sources is a sensitive issue and has to be taken into account. Although in the case of most applications, such as corridors, garages or staircases, the presence of disturbing luminaires can be excluded by design. Strategies to overcome this problem are possible (such as frequency swopping).

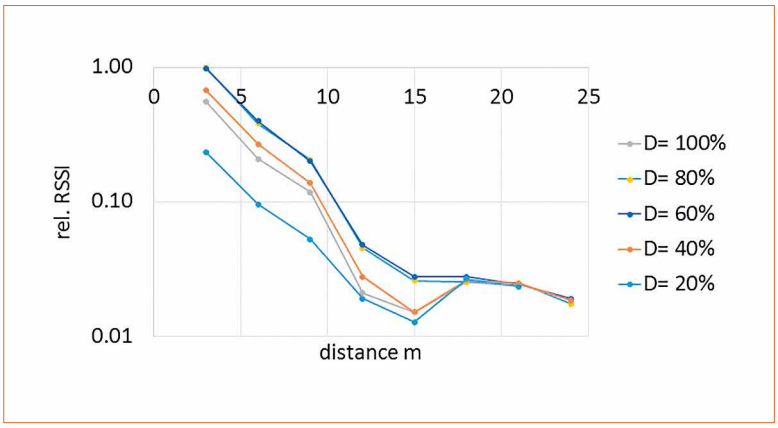


Figure 11: Relative RSSI dependent on distance and dimming level

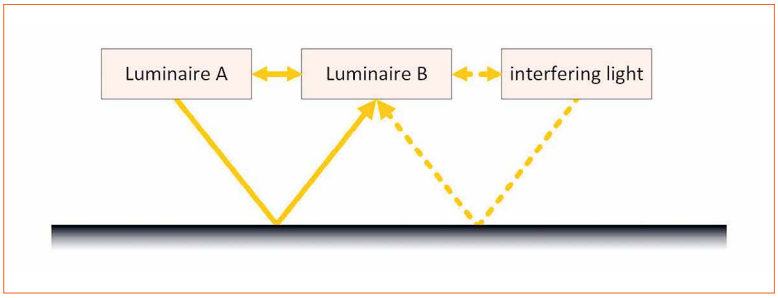


Figure 12: Setup to evaluate immunity to interference

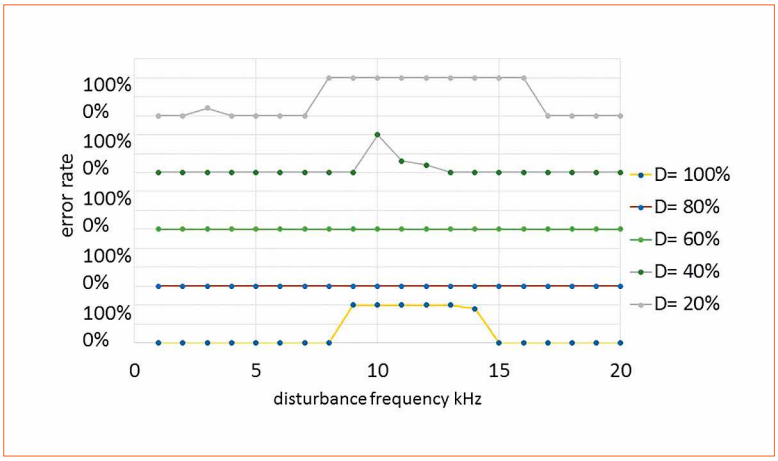


Figure 13: Error rate dependent on disturbing frequency and dimming level

Conclusions

A low-cost lighting system communicating through VLC was developed, in order to show feasibility. A luminaire, detecting movements in its region, can radiate messages to surrounding luminaires. These in return can receive messages and estimate RSSI. A swarm behavior can be programmed, without the need to address the luminaires. The system is robust against different environmental conditions and against sources of disturbance. The System works well in the range of 0 to 20m distance between luminaires. Extraneous LED luminaires or light sources, which are dimmed with PWM, and which use PWM frequencies near to the FSK frequencies of the VLC luminaires, can still disturb the system. ■

Remark:

HSi Elektronik is patenting the solution presented in this paper [6] and is now working on the engineering of the VLC luminaire, developing a product out of the functional models. Further tests and validations are needed, especially connected with real applications. Long-time tests are still pending.

Appendix:

Compensation of self-generated light During the development it became clear, that reflections of the self-generated light are a major obstacle in achieving reliable communication over long distances. We first tried to dim the luminaires through PWM at a higher frequency compared to the FSK frequencies (for example 25 or 50 kHz). Despite the higher frequency, the reflections of the self-generated light were a major disturbance for the receiver circuit. When we changed from PWM to current regulation, we noticed that the inevitable ripple of the current controller also had frequency components in the FSK band and was able to disturb the receiver. Therefore, we analyzed methods for the reduction or elimination of the influence of the self-generated light. These measures contribute to the extension of the operating distance of the luminaires.

We evaluated and partially tested the following methods:

- A cheap optical shading is realized around the receiver photo diode (implemented solution in the final design)
- An additional inward oriented photo diode is connected to the input of the transimpedance amplifier (TIA) through a weighted current mirror. The injected current is subtracted from the current of the outward oriented photo diode. Through proper calibration, the compensation of the self-generated light is possible
- An additional array of smaller and switchable inward oriented photo diodes, whose current can be subtracted from the current of the outward oriented photo diode, are connected to the input of the TIA. Through proper switching of the photo diodes array, compensation of the self-generated light can be achieved
- A controllable LCD shutter is placed between an additional inward oriented photo diode and the power LEDs. The inward oriented photo diode is connected to the input of the TIA and its current is subtracted from the current of the outward oriented photo diode. Through calibration of the LCD shutter, compensation of the self-generated light can be achieved

The last method (LCD shutter - Figure 14) proved to be the best one. It was possible to achieve 28 dB of suppression of the signal generated by self-generated light. Although a small LCD shutter can be bought for only half a dollar, the implementation of this solution was no longer pursued during the project.

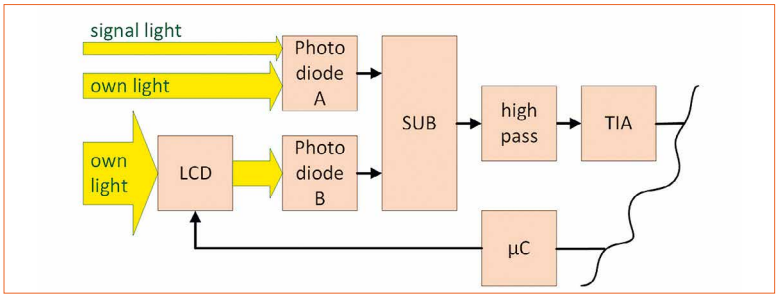


Figure 14: LCD shutter for the compensation of self-generated light

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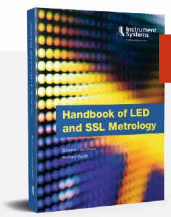

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Tissue-Specific & Biodynamic Control of Surgical Lights - a Future Lighting Concept

A modern surgical light offers the surgeon the opportunity to control the optical components and the color temperature via a control unit. One of the main challenges when considering the visual task of a surgeon is the distinction of different tissues or tissue-conditions. Color perception and color differences can be optimized using appropriate spectral power distributions (SPD) considering the reflection properties of biological tissues. However, the technical term "color temperature" is not sufficient to describe this optimization problem. Besides this optimization problem, each light source with an emission within blue spectral range at around 480 nm causes a non-visual effect on the operating-room staff. This could influence the circadian rhythm or lead to concentration impairments. Therefore, this article describes the visual task of a surgeon and the state of the art of modern operating-room lighting systems. Essentially, Prof.Dr.Dipl-Phys. Paola Belloni, Professor, and M.Sc. Alexander Gaertner, Research Associate, from the Institute of Technical Medicine (ITeM) at the University Furtwangen, present a new method to measure the reflection properties of biological tissues and discuss a new approach.

Light has always been around us and it is influencing our life in multiple ways, potentially many more than we realize. Life and its physiological mechanisms evolved in a world of continuous change between day and night. Therefore, it is reasonable that light and its absence directly affect the physiology of humans just as all other living organisms. Discovering these molecular mechanisms J. Hall, M. Rosbash and M. Young got awarded with the Nobel Prize in Physiology or Medicine in 2017 [1]. For many years, the lighting industry was only driven by values like illuminance or electrical efficiency. However, industry and the society's sensation towards lighting changed over the past few years. Nowadays, terms like human centric lighting (HCL) and the demand for individual, application-specific lighting solutions represent an essential part of modern lighting concepts. This particularly applies to special workplace illumination, like the illumination of an open surgical field in different surgical cases. Thus, we introduce a surgical lighting concept considering biodynamic illumination just as an individual, application-specific lighting approach for tissue-specific illumination.

Requirements of Surgical Lights

Successful lighting concepts are developed by considering the requirements of the specific visual tasks. This includes environmental characteristics like working conditions, daylight exposures and specific needs of the users that can vary with age and gender.

A fundamental requirement to lighting systems and especially surgical lighting systems (SLS) is safety, since lighting directly and indirectly influences the health and the comfort of patients and the medical staff. The most important requirements, safety relevant parameters and restrictions are standardized in the International Standard IEC 60601-2-41 for medical electrical equipment [2].

The first and probably most obvious function of an SLS is to provide

enough light in the surgical field. The standard IEC 60601-2-41 defines an illuminance threshold for a single surgical lamp between 40,000-160,000 lx to guarantee adequate illumination for surgeries with poor reflectance from the surgical field and prevent unreasonable energy exposure.

An additional relevant aspect is the illuminance uniformity in the surgical field. In the past, surgical lights have not been able to provide high illuminance values coupled with a uniform light distribution inside the surgical field. The typical result was a maximum central illuminance showing a steep decrease to the edge of the illuminated field. The edge of the illuminated field is defined as the region where 10% of the central maximum are still detectable. According to IEC 60601-2-41, a light distribution with a minimum ratio of d50/d10 ≥ 0.5 (the light field diameter with 50% / 10% of the central illuminance) must be ensured by an SLS. Besides a central illuminance maximum and a uniform distribution, it is also recommended that an SLS should be able to flexibly adjust the size of the illuminated area. In fact, different surgeries and surgical cases require specific shapes and sizes of the surgical field. Therefore, it follows that depending on the light distribution luminance discrepancies in the field of view (FOV) could result in glare effects. Unfortunately, these undesired glare effects are even more amplified if the illuminated biological tissue in the surgical field is highly reflective.

The last very important requirement of an SLS is the prevention or best possible reduction of any cast shadows. Cast shadows are generated by the surgeon's hands or instruments utilized during surgery. In any case, this reduction has to be realized without significant impairment of the visualization of tissues and structures in the surgical field.

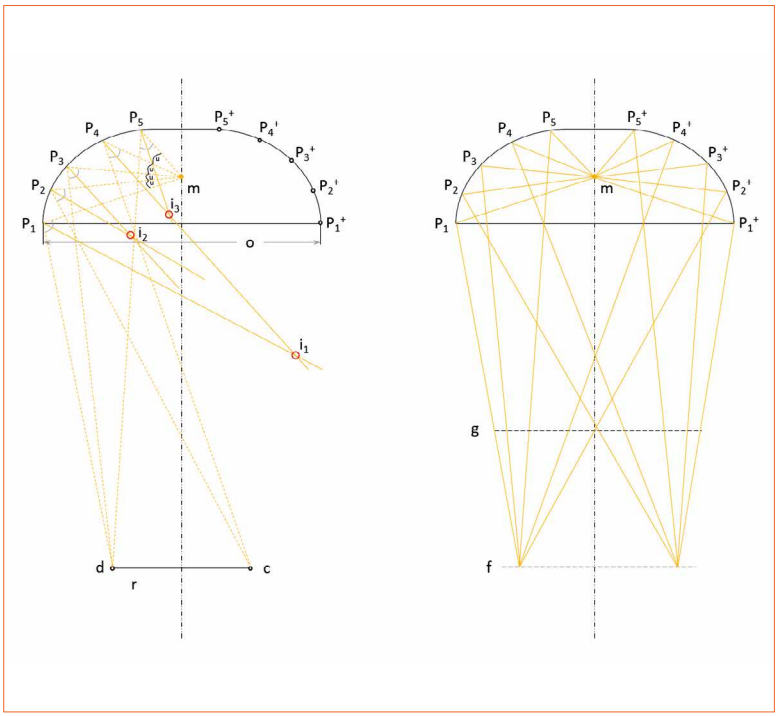

Figure 1:
Cast shadow reduction by zone separated main reflector system, where every zone illuminates the whole field [3]

State-of-the-Art

Cast shadows

Cast shadow reduction is the reason why surgical lamps typically have big diameters. The surgical field is illuminated from different directions by means of overlapping light cones to prevent undesired shadows and to preserve contours of the tissue structures. One of the oldest lighting solutions makes use of a large main reflector with optimized facets and a centrally positioned light source.

The faceted reflector projects the luminance of the light source on spatially separated zones that overlap to uniformly illuminate the whole surgical field. Figure 1 shows the original drawing of the patent from 1952 [3].

Today this technology is typically realized with a system of separated optical modules based on TIR-optics and LEDs mounted side by side inside the lamp housing.
A further optimization of this solution

Figure 2:
Stryker Berchtold Chromophare E558/ E778 Surgical Light. The SLS combines separate optical modules based on high-performance LEDs and a two-stage optical system and a central reflector. Color mixture is realized by superposing the light cones on the surgical field with adjustable CCT between 3,600-5,000 K [4]

is to combine specifically developed lenses for the LED modules with an additional reflector that overlaps the light cones of the single LED modules to reach the desired uniformity on the surgical field [4].

Shadow dilution

Another issue is the shadow dilution described in the standard IEC 60601-2-41. This approach tries to simulate the reduction of central illuminance due to the partially covering of the light-emitting surface by the heads of the medical staff. In some cases, where more than one surgeon is involved in a surgery, this could dramatically reduce the usable luminous flux of the SLS. A state of-the-art solution for this problem is provided by enlarged light emitting surfaces. However, space inside the operating room is precious, so this solution is, in some cases, difficult to realize. Therefore, SLS with an automatic shadow dilution mode are available on the market [5]. A sensor system detects objects in front of the light-emitting surface and the affected parts of the lighting system are switched off while the flux of non-affected parts is increased. Such a solution can effectively compensate the reduction of central illuminance by covering the light-emitting surface. However, the challenge in this method is to perform these accommodations in a time scale that will not be perceived as too quick and disturbing.

Adjustment of the surgical field

Nowadays, there are many different solutions on the market that meet the need of a flexible surgical field area. The classical geometrical-optical solution is to mechanically defocus the light source inside the optical system [6]. Other approaches are based on tilting optical units or overlapping different illuminated field sizes that are accordingly controlled. However, there are also solutions available that come close to the vision of a self-adapting SLS. Here, a sensor system is measuring the distance between surgical lamp and illuminated field. By changing the distance, the SLS automatically aligns the light distribution to maintain the original size of the illuminated area [5].

Depth of illumination

Different surgical cases imply different geometric requirements, not only in the size, but also in its depth of the surgical field that must be able to illuminate deep cavities. The depth of illumination is defined as the distance along the optical axis where 60% of the central illuminance is reached. Typically, the optical construction of a static SLS can include more than one focus level to increase the depth of illumination. Additionally, a continuous measurement of the distance between light emitting surface and surgical field can be carried out to adjust the focus of the SLS. Obviously, each technique will always provide a compromise between depth of illumination, size of the illumination field and light distribution curve.

Spectral properties

The spectral properties of an SLS are a further important quality characteristic. Parameters like color rendering index (CRI) are well known and the standard IEC 60601-2-41 restricts illumination for SLS to a minimum of CRI≥85. However, CRI does not adequately describe the quality of a LED-based SLS to reproduce colors of biological tissues. Other state-of-the-art approaches suggest an adjustment of the correlated color temperature (CCT) for surgical lighting. However, CCT is never an appropriate value to describe the spectral distribution of an SLS. Only together with the CRI could it be used as a kind of quality attribute. Current products can quite easily adjust the CCT between 3000 K and 6000 K, which is also the range suggested in the standard IEC 60601-2-41 [2].

Biodynamic Control

Light influences not only the visual but also the non-visual system of humans and every other living creature. The non-visual influence directly affects the human physiology and is one of the most important drivers controlling the circadian rhythm.
The suprachiasmatic nuclei located in the brain is the superordinate internal master clock regulating the sleep-awake cycle. Evidence for such circadian activities can be proven by investigating hormonal changes of Cortisol and Melatonin during the day and night [7].
By continuous exposure to time shift, stress, sleep deprivation or incorrect lighting, negative consequences like Circadian rhythm sleep disorders (CRSD) might occur. Potential short-term effects are a loss of attention or impairments to process information and memory. These potential hazards must be mentioned discussing the biodynamic control of surgical lights within the scope of a holistic SLS concept.

The physiological mechanisms of the visual and non-visual system differ heavily. Cones and rods in the human eye are stimulated and the light (visual) stimulus is converted to an electrical signal that is transmitted to the visual cortex, where the image is created. On the contrary, the photoreceptors of the non-visual system, the intrinsically photosensitive retinal ganglion cells (ipRGC), affect the human body by releasing hormones in the bloodstream [8]. The effects on the non-visual system are first dependent on the total exposure of light (luminous intensity of light per time) and second on the angle of the light incident in the human eye. The ipRGCs have their own photopigments, Melanopsin, which reaches its maximum sensitivity at wavelengths of 480 nm. IpRGCs influence the circadian rhythm just as the pupil reflex and alertness. The ipRGCs interact with rods and cones, since they are interconnected by (rod) bipolar and amacrine cells respectively.

Furthermore, the ipRGCs are less sensitive to lower intensities compared to the cones and especially the rods. It can be summarized that there is a complex and task-specific interaction between all photosensitive cells inside the eye of the non-visual system.

Considering all this information for the development of a biodynamically controlled SLS, there could potentially be great influences on the medical staff and patients, since an SLS provides high illuminance levels compared to general lighting systems. In 2005, a study from Berchtold GmbH & Co KG, together with the Technical University Ilmenau was published, investigating the error probability of surgeons under illumination of an SLS with 4300 K compared to 3400 K. The study proved that surgeons are less prone to errors during surgery under illumination with higher color temperatures in the winter period [9]. Over the past 15 years, there has been an extensive growth of knowledge about these mechanisms. However, to integrate a biodynamically controlled SLS in an operating room, several issues like the relevant visual task of the surgeon and the surgical procedure itself have to be investigated.

Tissue-Specific Control

Besides the biodynamic control of a surgical lamp, a second major goal to achieve is the development of a tissue-specific control. The aim of such an additional feature is to enhance the visualization of biological tissues and allow the surgeon to distinguish between different tissues, particularly nerve and cancerous tissue. A flexible, spectrally tunable light source is fundamental to realize this illumination concept and perform an optimization. There are three technical possibilities to tune SPD of light sources. First, the SPD can be selectively controlled using a light modulator – either a prism or a digital micro mirror device tuning light provided by a xenon light source [10]. Second, color filters can be applied to a broadband light source to selectively reduce specific wavelengths [11]. Third, multiple narrow-band LEDs can be used to individually adjust the SPD of a light source by increasing or decreasing the driving currents of LEDs or using pulse width modulation techniques [12].

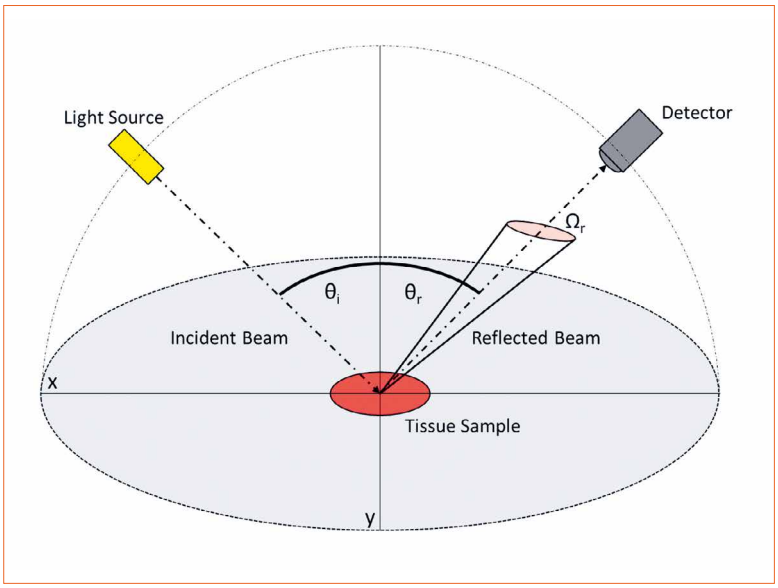

Figure 3: Measurement method for goniometric acquisition of the BRDF of biological tissue samples ex vivo. The sample is fixed on a cooling plate while light source and detector are rotatable

To realize the concept of a tissue-specific illumination and perform the optimization, the reflection properties of the sample must be known. Since reflection characteristics of anisotropic materials like biological tissues are wavelength- and angle-dependent, we measure bidirectional reflection distribution functions (BRDF) of tissue samples ex vivo. Systematic and wavelength dependent BRDF measurements of biological tissues are not available in the literature and libraries of illumination design software. Few researchers have studied the reflection properties of biological tissues by focusing on the BRDF measurement of different types of human skin [13].

Compared to conventional material samples (e.g. aluminum or stainless steel), the BRDF measurement of biological tissue samples presents a huge challenge for several reasons: Tissue samples degrade over time and are heavily temperature dependent and moisture sensitive. A further aspect not to be overlooked is how to correctly prepare the samples for the measurement. Cutting the samples on the surface to be measured, for instance, will strongly affect the scattering and therefore the result of the measurement. On top of that, each biological tissue sample is a unique specimen. This means that even guaranteeing equally constant measurement conditions will not necessarily lead to equal results for two specimens of the same type of biological tissue.

The spectral optimization of the light source is performed through the following steps: First, the BRDF of a point of interest $(R_P(\lambda))$ and its surroundings $(R_U(\lambda))$ are determined. Then, $S_n(\lambda)$, a suitable initial SPD is chosen for each tissue. For instance, it is known that wavelengths in the range between 450-550 nm are helpful to discriminate blood vessels from its surrounding tissue [14]. The ratio of both, reflection spectrum $R_P(\lambda)$ and $R_U(\lambda)$ forms a relative reflection function $RR(\lambda)$. This relative reflection function provides evidence on the spectral regions with the greatest discrimination of the reflection spectra of $R_P(\lambda)$ and $R_U(\lambda)$ [15]. A specific weighting factor g_n is assigned to every LED ΔI_n that refers to the relative reflection function $RR(\lambda)$. The higher $RR(\lambda)$ of certain wavelengths, the higher the weighting factor gn of the LEDs ΔI_n. Finally, the optimization is carried

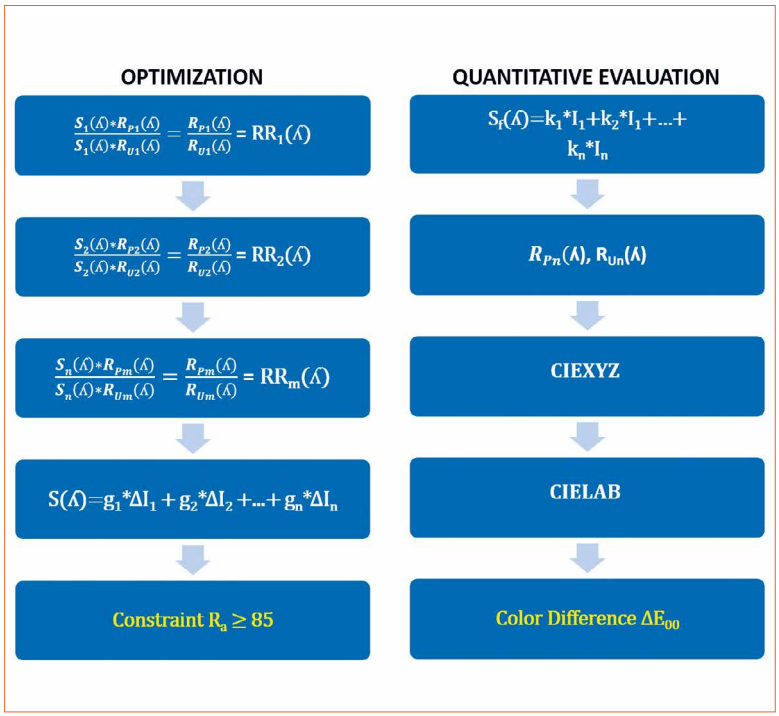

Figure 4:
Optimization flowchart

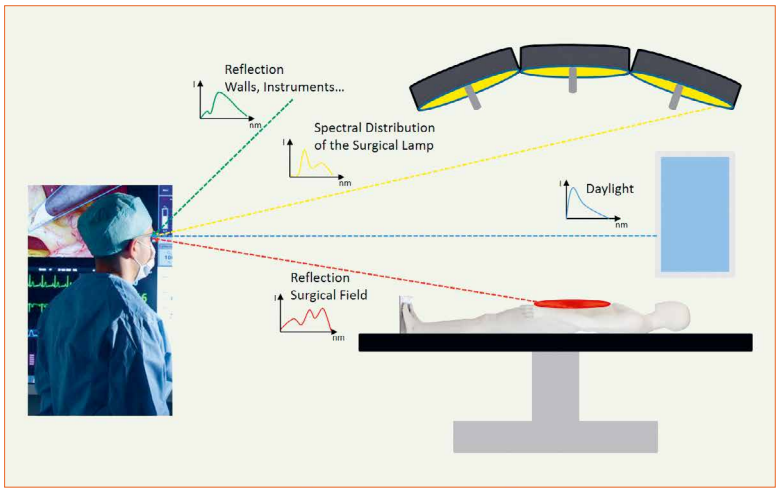

Figure 5:
Description of the complexity of the surgeon's visual task: Not only the spectral distribution of the SLS but also the reflection properties of medical instrumentation and walls influence the visual perception of the medical staff. Additionally, daylight can occasionally be available in operating rooms and will therefore influence the circadian rhythm

out by adjusting the intensity of the LEDs with the constraint Ra ≥ 85 given by the International Standard IEC 60601-2-41 [2]. The new spectrum $S_f(\lambda)$ can further be described by the adjusted intensities of the LEDs In and their specific weighting factors k_n. Aim of the optimization is to maximize the target function ΔE_{00} for the new spectrum $S_f(\lambda)$. The quantitative evaluation of the new spectrum $S_f(\lambda)$ is performed by determining the color differences ΔE_{00} based on the reflection functions of the point of interest $R_{Pn}(\lambda)$ and its surroundings $R_{Un}(\lambda)$ under the new spectrum [16]. The color difference between these reflection functions is calculated by transferring the reflection spectra to their related color coordinates in CIEXYZ color space. From there, the color coordinates are translated to CIELAB color space, since subjective color differences of the visual perception are better characterized in CIELAB than CIEXYZ. Then, the color difference between the two points $R_{Pn}(\lambda)$ and $R_{Un}(\lambda)$ determined by their reflection functions can be calculated from the color coordinates L, a and b.

In summary, this optimization is the process of permanent adjustment of the new spectra and the quantitative evaluation of ΔE_{00} to find the optimal spectrum to illuminate a certain tissue and receive the greatest color differences between a point and its surroundings, respectively.

The Vision of a Future Lighting Concept

A future lighting concept could potentially include both, tissue-specific and biodynamic control of surgical lights to optimally support surgeons. However, before realizing such lighting concepts in operating rooms, all environmental aspects that influence the visual task of surgeons and medical staff must be analyzed and understood. Figure 5 shows the complexity of factors affecting the visual task of the surgeon, which includes far more than the reflections from the surgical field.

In addition to the reflection properties of the surgical field, the whole visual perception of the surgeon is influenced by the spectral distribution of the SLS, the reflections from walls or instrumentation and occasionally, if present, by daylight.

Only in this way, can the biological effects of the illumination usefully support the previously defined relaxation and concentration phases for the staff during surgery. Of course, before and after surgery, the biodynamic control of a SLS can positively influence the circadian rhythm of the surgeon, for instance, in decreasing the Melatonin level during the preparation phase.

Future developments focus on implementing multiple sensors close to the surgeon collecting information on spectral and intensity properties of all incident light relevant to the visual task. The SLS automatically then adapts intensity, spectral properties and FOV considering the data recorded.

In conclusion, any improvement of the SLS must be compatible with the strictly defined medical procedures in the operating room and can only be implemented in collaboration with the medical staff. Of course, a holistic SLS concept will always result in a trade-off between tissue-specific and biodynamic optimization. ■

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The Trend Towards Improved Light Quality Continues at LFI

Since the introduction of LED lighting, there have been many "mega trends" but not all of them have been sustained. But, no wonder: Many of the trends originated in the minds of people in marketing departments and weren't derived from customer requirements. The truth is – most customers aren't interested in fancy technology phrases because lighting, unlike a smartphone, is not a gadget. Customers understand that light is much more than that and the industry promised them that lighting would surpass their expectations with the introduction of LEDs and OLEDs. It is important that the industry follows the true requirements of customers, like easy handling and healthy and appropriate light quality. At LightFair 2019, the industry showed that it understood! Arno Grabher-Meyer, Editor-in-Chief at LED professional was there and has written a detailed report.

This year LightFair International celebrated its 30th anniversary with the slogan "30 years of innovation. 30 years of memories." During those 30 years, LightFair has attracted the attention of visitors from all around the globe and has become the leading fair for companies to introduce and present new and trending products to the US market.

Almost as if the leading exhibitors wanted to thank the initiators, this year they brought particularly interesting, advanced LED products that are ready to lead the way, and waiting to be introduced to the market, to the exhibition floor.

Opening the Show with a Crowning Point

The Awards Ceremony, which took place immediately before the doors to the exhibition halls were opened, was the first highlight. It couldn't have been an easy task for the judges because of the huge number of very high-level submissions. Out of 181 products in 14 categories, they finally managed to identify the best of the best and selected 14 category winners out of 42 highlighted products. But it didn't stop there: Out of the 14 category winners, the judges also chose the winners of the Innovation Award, the Judges Citation Award, the Design Excellence Award and the Best Product Award.

Attending this ceremony is a mandatory for every visitor who wants to learn about the "must see" products and companies. On the other hand, this might also cause some stress because it isn't only the winners that offer interesting properties, features and specifications. So three days may not be enough for a visitor to see everything worth seeing!

Categories and Winners Showcase:

Non-Luminous Products: Research, Publications, Software and Specialty Hardware
Illuminating Engineering Society (IES):
ANSI/IES RP-8-18, Recommended Practice for Design and Maintenance of Roadway and Parking Facility Lighting

The Illuminating Engineering Society has released ANSI/IES RP-8-18, Recommended Practice for Design and Maintenance of Roadway and Parking Facility Lighting. The 440-page document is not only a substantial revision to the previous ANSI/IES RP-8-18, but it is also an aggregate of topics from 12 IES roadway-related lighting documents, all of which RP-8-18 now supersedes, along with two design guides from the Transportation Association of Canada. This comprehensive document took over two years and 100+ committee volunteers to complete, and it was developed under the rigorous ANSI process.

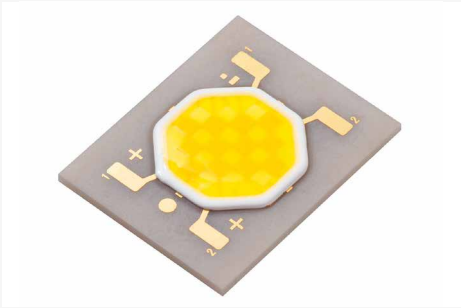
Lamps: Conventional, Retrofit and Replacement
Signify:
InstantFit T8 Visible Light Communication TLED by Signify

InstantFit LED T8 VLC enables Philips' Indoor Positioning System in a retrofit TLED. It features patented Philips Visible Light Communications (VLC) technology enabling location-based services without any additional fixture hardware while delivering high-quality light & 50% energy savings. It represents a breakthrough for retail stores to harness the value of VLC without the expense of a luminaire renovation. Retailers gain shopper insights to optimize store lay-out, planograms, staff allocation and marketing. Shoppers find products with pinpoint accuracy while receiving offers & product info.

LED / OLED Chips and Modules - Technical Innovation Award
SLD LASER:
LaserLight MicroSpot Module

The LaserLight MicroSpot Module is the world's first 400 lumen module offering a 2 degree collimated beam from a 35mm optic. LaserLight MicroSpot Module combines the highest luminance source, LaserLight SMD, with a TIR collimating secondary optic. The result is a compact module with very high candlepower intensity, narrow beam angle, sharp beam edge cutoff, and efficient beam shaping capabilities with diffusers. Module enables the development of micro luminaires with up to 1000m beam range by ANSI FL-1 spec. Applications include outdoor, architectural, entertainment, and security lighting.

LED / OLED Chips and Modules - Judges Citation Award
Nichia America Corporation:
Color Tunable COB

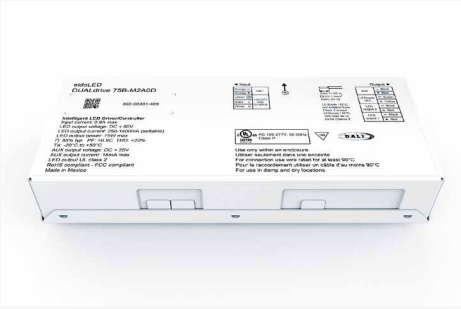


Nichia's Color Tunable COB series is ideal for many applications, such as commercial, retail spot lights and residential downlights. Retail stores can change the light color based on their display or objects in it. Families will be able to change the color temperature of their home to best suit their natural biological rhythms. Nichia's color tunable COB expands the market potential for future lighting fixtures and environments. With the goal of enriching people's lives, Nichia will continuously strive to improve the quality of light.

LED / OLED Chips and Modules - Judges Citation Award
Samsung Electronics:
Samsung E-series

New tunable COB, E-series, which achieves the industry-highest COB light efficacy of 140 lm/W and the best color mixing. Unlike conventional methods, the E-series uses white and blue CSP chips and phosphor dispensing to improve light efficacy and color mixing by eliminating any interference between red and green phosphors. The white CSP chip emits high-efficiency warm white, while light emitted from the blue-chip supplies cool white by passing through a dispensed phosphor. Will open a new market for COB LEDs and further enlarge human-centric lighting market.

Ballasts, Transformers, Drivers, Systems and Kits
Acuity Brand Lighting, eldoLED:
eldoLED 75W LED driver product family (75W/L and 75W/B)



Our company mission is to enable Quality of Light for our OEM customers, while allowing maximum flexibility in component selection. This resulted recently in our fully programmable 75W driver family – a unique product in the market since it has best-in-class dimming performance down to 0,1% through our Hybrid HydraDrive dimming technology. Furthermore, it is unique in Dim-to-Warm and Tunable White, powered by LightShape, plus it meets the IEEE1789 flicker guidelines. All 75 W drivers are UL Class P listed, to ensure maximum component flexibility. Control options include 0-10V and DALI-2.

Track, Display, Undercabinet and Shelf
Acuity Brand Lighting:
Juno Wireless Control LED Track Fixture Family

The Juno Wireless Control LED Cylinder Track Fixture Family enables dynamic beam shaping, aiming, dimming & CCT adjustment from a secure wireless platform. Never has precise remote control of a broad range of functions been attainable. Rotation & tilt in less than 1/10-degree increments allow exact targeting even over long throws. A patent pending clover leaf TIR optic w/rotating variable gradient lens adjusts from 16° to 47°. CCT can be set from 2700-6500 K or configured for Warm Dimming, maintaining 90 CRI & 3 SDCM. A custom mobile app enables simple fixture/group/scene/space commissioning.

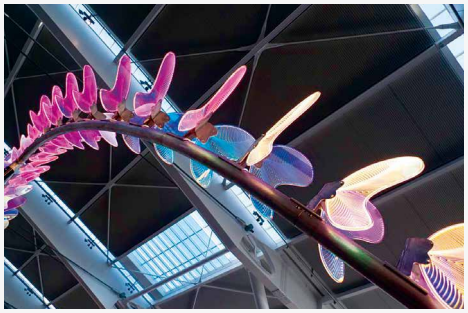
For the third time in a row, SLD Laser received the Innovation Award

Erick Swenson proudly accepted the Judges Citation Award for Nichia's tunable COB with a focus on highest light quality

Recessed Downlights, Wall Washers and Multiples - Most Innovative Product of the Year
Ecosense:
Lore

Lore is a fully adaptable luminaire family that features our newest optic & driver technology, engineered for precise beam performance and beautiful dimming. Every fixture in the Lore family debuts & shares our power, light, optic, wireless, and battery backup building blocks, which means Lore provides consistent, predictable, performance from fixture to fixture across all fixture types. Lore also debuts EcoSense's latest 'Lingo' digital platform architecture and Auto Sensing Protocol Technology, which makes Lore extremely flexible today & the infinitely adaptable tomorrow.

Indoor Decorative
Lightpanel (USA) Inc.:
Lightpanel AIR ColorWheel



The Lightpanel AIR LGP's are German designed, LED light panels that deliver maximum light exposure while maintaining homogeneous light distribution. Manufactured using advanced laser technologies, the AIR can be custom cut and designed to any shape and size. Coming in at only ¼" thin the AIR series is available in 3000 K, 4000 K, 5000 K, 6500 K, RGB, and RGB+W color temperatures. Versatile: can meticulously cut any shape or size and engrave any pattern Proprietary: special LGP laser software for optimized dot-matrix patterns Dependable: integrated automated digital control production processing.

Parking, Roadway and Area Luminaires
ANP Lighting:
EQ Series

The EQ Series is a contemporary styled, outdoor decorative site lighting collection designed for visual comfort, comprising of three sizes of post top and wall mount, including a companion bollard for pedestrian/site lighting applications. Visual comfort is achieved with a high-efficiency light guide featuring Type II, III, IV & V distributions, ranging from 2700K to 4000K CCT values. An available dynamic white, symmetrical distribution LED solutions allows for greater flexibility. All luminaires can be configured with controls options to enhance efficiency and meet CA Title 24 requirements.

Sports, Step, Landscape, Pool & Fountain Luminaires
Eaton:
Ephesus Lumadapt 8

Eaton's Lumadapt 8 LED sports lighting system alleviates the concerns of facility operators hesitant to purchase sports lighting for fear of being constrained by the limitations of most of today's sports lighting. Lumadapt allows operators to buy the features they need now and then remotely update and expand as needs change or new features become available. The smart cloud approach connects the entire system, providing expandability with a wide range of a-la-carte options including RGBA color, beam tuning, color temperature tuning, remote health monitoring, a dynamic scene builder and more.

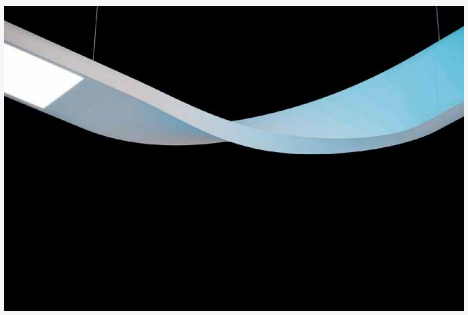
Samsung's CCT tunable E series COB was honored with the Judges Citation Award

Ecosense's Lore luminaire family, a highly modular, feature rich and easy configurable concept, won the Product of the Year Award

Controls: Components, Sensors, Interfaces and Software
Cimcon Lighting, Inc:
NearSky 360

CIMCON's NearSky™ 360 Platform is a next generation of Edge computing platform which captures, analyzes, aggregates and communicates sensor data within a Connected City. This Platform comes with a powerful quad core processor, LTE support and is designed to help quickly deploy various smart city applications such as Environmental, Noise, Parking, Traffic and Security Monitoring. An ANSI compatible C136.41 7-pin connector at its base and ANSI compatible 7-pin receptacle at its top ensures quick "plug and play" installation and easy positioning.

Commercial Indoor: Troffers, Suspended and Surface Mounted - Design Excellence Award
Acuity Brands Lighting:
Peerless Renna

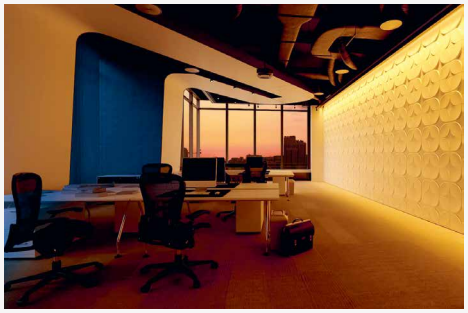


A simplicity of form provides compatibility with modern architecture, especially open and deconstructed ceilings. The 4" housing width and minimal 1/4" lightguide bezel supports a balance of visual comfort with a minimalist physical presence. Lightguide technology supports a low-profile 1" tall form while producing a uniform spread of luminance for both a glare-controlled downlight distribution and a concealed source asymmetric wall wash. Linear injection molded optics produce a performance indirect distribution for maximal uplight coverage, creating even illumination throughout the space.

Industrial, Vandal, Emergency and Exit
Meteor Lighting:
Whiz 2.0

The Whiz 2.0 is Meteor Lighting's latest Architectural High Bay that supersedes the Whiz, a flagship product of the company that has been specified in over 1000 projects to date. The Whiz 2.0 is sleeker, compact and more architectural than any other High Bay offering of its type in the market. This distinctive architectural solution is perfect for commercial interiors with high open ceiling, including; atriums, lobbies, convention centers, and airport terminals. With an IP65 weatherproof design, the Whiz 2.0 is also suitable for exterior entrances of office buildings and canopies.

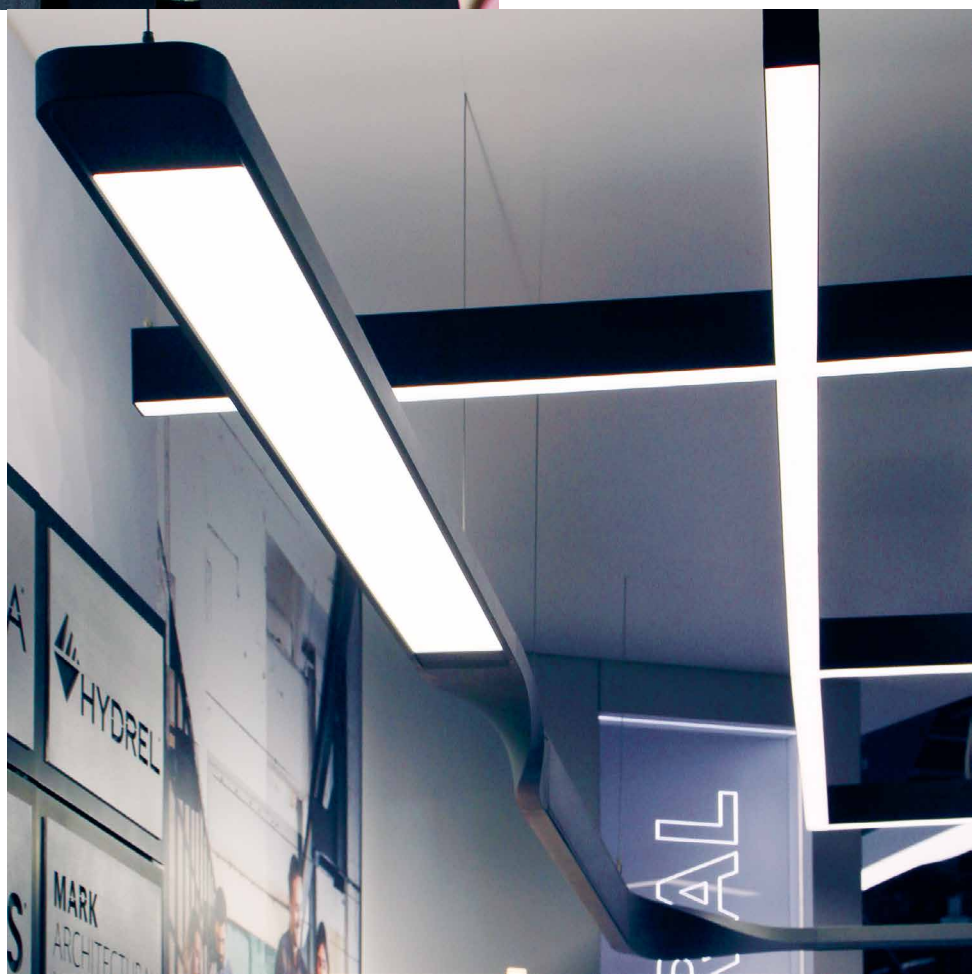
Dynamic Color, Theatrical, Cove, Strips and Tape
Optic Arts:
Vintage Dim2



Vintage Dim 2 is a custom curve control driver with NFC programming ability for a touch and go set control. With an android based application, you can set and share your curves for tunable white, warm dim, color matching, curve matching, color calibration.

Acuity Brands Lighting, with their Peerless Renna luminaire was the lucky winner of the Design Excellence Award

The Peerless Renna from Acuity Brands convinced the jury with its simplified, straight forward design and greatest flexibility based on its modular approach



Control and Distribution Systems, Connectivity and Analytics

Silvair:

Silvair Commissioning

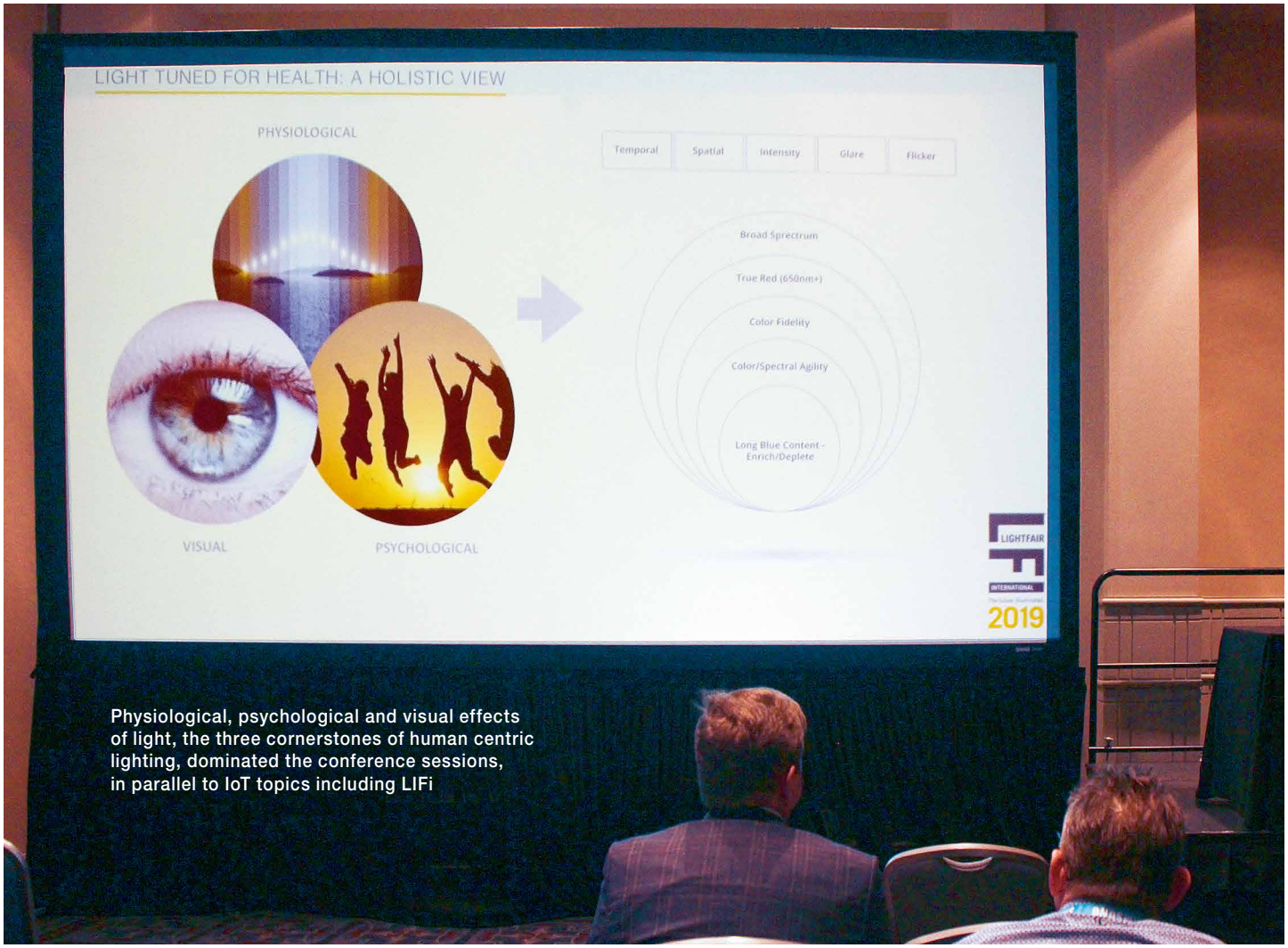
Silvair Commissioning is a set of tools for setting up and managing wireless lighting control systems based on Bluetooth mesh, the first wireless technology for professional lighting applications. To help all industry stakeholders unleash the full potential of this global standard, Silvair has built a platform that radically simplifies and accelerates the commissioning process in commercial spaces. It allows any lighting control parameters to be customized in accordance with current lighting needs or evolving energy codes. Silvair Commissioning includes a mobile app and a cloud-based web app.

The Conference, Tours and Special Events

In addition to the pre-conference, LightFair also provides a conference program during the show that primarily addresses lighting designers and planners. It offers all they would expect from basic to advanced forums and highly specific workshops. This year's big topics were health and well-being, and IoT. Considering the number of interesting exhibitors and that the show is limited to three days, visitors needed to carefully gauge which events they would choose and how much time they would use for visiting the show. If the focus of the visitor was on the fair, it was well worth it to attend the Award Ceremony mentioned above.

Selected Product Highlights Accompanied by Exciting Discussions

I would be lying if I claimed to provide a complete and representative overview of the show highlights. I was confronted with the problem of how best to make a selection of what to look at over the course of the two and a half days I was there. I relied heavily



Physiological, psychological and visual effects of light, the three cornerstones of human centric lighting, dominated the conference sessions, in parallel to IoT topics including LIFi

▲ With the new Luxeon Fusion, Lumileds explores new avenues, providing an all-in-one approach, minimizing stock inventory without compromizing simplicity of use and quality

on press releases and requests from agencies received before I got to the fair. I also had to be flexible because the winning products as well as the shortlisted products were well worth considering. Nevertheless, I will do my best to provide a comprehensive overview of the show and I do apologize if I missed anything relevant.

Components and light source manufacturers

A week before the show, Lumileds announced its new product line – Luxeon Fusion. They described it as follows: Combining the needs of many tuning technologies, including dim to warm and dynamic tuning for human centric lighting, Luxeon Fusion addresses CCTs from 1,800 K to 10,000 K with high color-rendering index (CRI)

▼ A top priority for Bridgelux is simplifying the system and reducing stock inventory, which, in turn, reduces costs. Their approach: Modularity and unlimited interchangeability

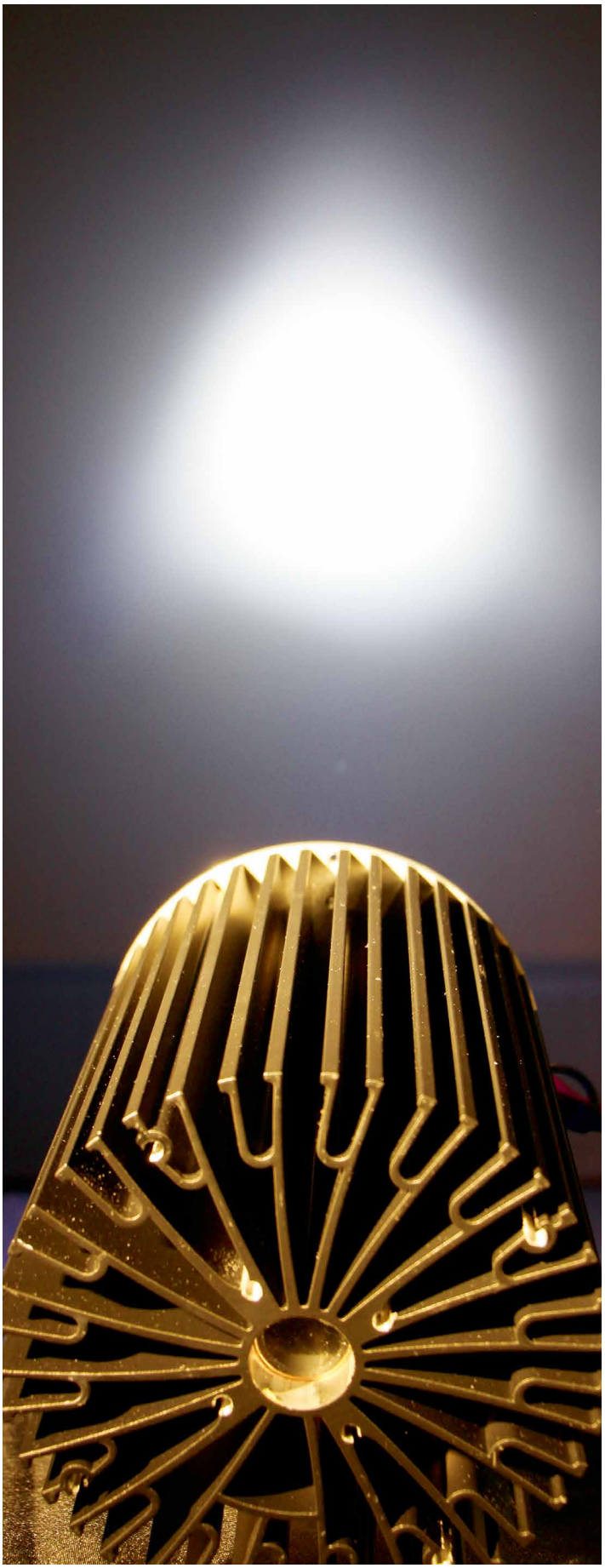
(>90 over 95% of range) and high color fidelity." Fine color tunable and CCT tunable modules in that range, didn't seem that ground-breaking to me, so I went to Steve Barlow, SVP at Lumileds and asked him to shed some light on the secret. Although he didn't disclose all the details he did tell me that three PC converted allow CCT tuning exactly along the black body curve and also above or below in the whole range. A clever selection of color points and spectra of the three LEDs makes the difference when compared to other solutions. While other systems have the disadvantage that on each end of the CCT tuning range they just utilize one LED, this new approach is much more balanced. In any case, all three LEDs are used. I'm happy to say that we will soon be providing a technical article about this solution in an upcoming edition of LpR – so stayed tuned!

Seoul Semiconductor demonstrated a number of interesting technologies and products at their booth, but the emphasis was on the latest findings on the benefits of their SunLike technology. SSC supported Dr. Octavio Perez's research on the melanopic response to different CCTs, light spectra and intensities. The surprising final results will be presented at LpS 2019 in Bregenz and an additional article with some background information will be published in LpR 75. Because I don't yet know all the details or the final results, I can only tell you this much: Light intensity is not the only parameter to consider and the shape of the spectrum has more influence than one would think. Mark McClear also joined the conversation and expressed his concerns about the component market, adding that SSC is healthy and in a very good position with its portfolio. He is especially happy that the scientific research results underline their estimation that the SunLike approach, which mimics the spectrum of the sun, has advantages over traditional LED concepts. Additional studies, that will be published soon, show similar results.

American Bright Opto serves very diverse markets with their products. Accordingly, the concepts and products presented were very different. While their offering in the lighting domain is dominated by simplification e.g. with California xxx regulation compliant AC products, they provide LEDs with integrated voltage limiting protection circuits for automotive. George Lee, president and CEO explained that these are not the main business lines of the company. The company, founded in 1981, has their strengths in products for printers and IR modules for positioning tasks and similar applications.

Bridgelux had already announced the release of drivers and controls gear to simplify and streamline product development with their CoB LEDs. NFC parametrization of the driver is standard, and a modular approach to allow different controls and communication standards was chosen. Between the drivers and the communication modules, a proprietary interface using an RJ45 CAT5 connection was developed. Surprisingly, Bridgelux will disclose details to clients who want to design their own drivers or communication modules. The product line will be extended successively. With this step, the company is entering a new field and is increasing its offers to its customers.

Luminus Devices introduced a new CoB with a small 3.5 mm LES called Pico-CoB for compact narrow angle applications. They also promoted



▲ **Amongst other products, Luminus impressed with their demonstration of the opportunities their unique "Large Chip" product line, in combination with LensVector's tunable lens can bring**

two existing product lines: Their CoBs with filled cyan gap and their unique Specialty White LEDs. While the first impresses with its improved white-rendering capabilities, the latter "Large Chip" product allows single chip solutions with high punch and narrow beam angle for applications like beamers or search lights. The one demonstrator for this application was equipped with LensVectors dynamic beam angle shaping technology.

OLEDworks presented their established portfolio of products. While they did not come with brand-new products, they reported success in improving efficiency and ongoing research on a tunable-white respectively dim-to-warm OLED solution. Giana Phelan, Director of Business Development, could not exactly tell when these advanced and new products will be market-ready. She expects that it should be within the next 12-18 months. I'm interested in seeing if this will become a highlight at Light + Building or LightFair 2020.

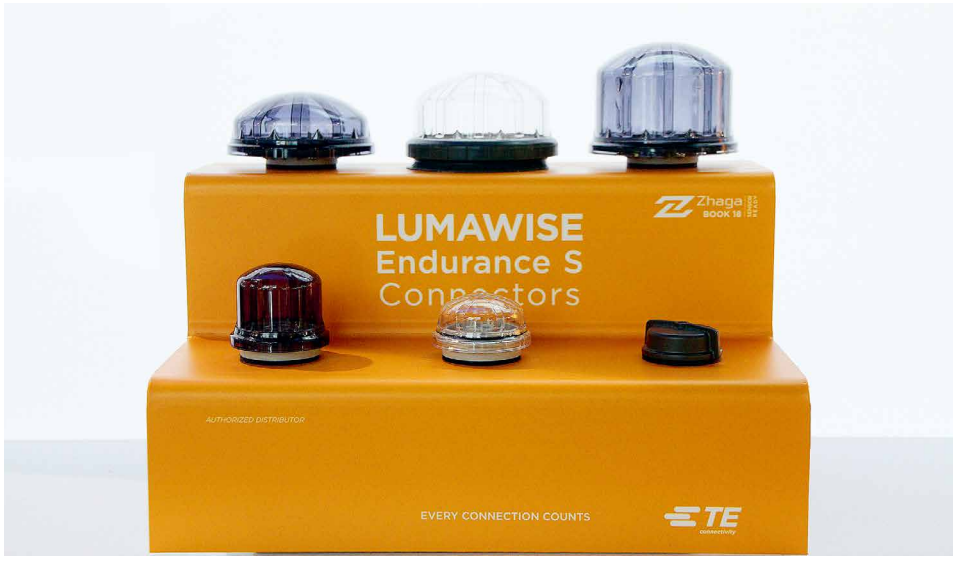
Like some other companies, Kopp Glass identified UV lighting as a new business field. One important request comes from horticulture. Lenses to direct the light where needed are inevitable for an efficient and cost-effective application. Material properties are crucial. The difference between a system without optics and one with optics was demonstrated at their booth. By using fluorescent material, the difference became apparent for the visitor and could even be documented by taking a photo. More details about material requirements, properties and specification can be read in the article "Transparent Material Considerations for UV Optics in Horticultural Lighting Applications" on page 66 of this issue.

Silicone optics specialist Sur-Seal presented first engineering samples of a highly robust silicone optics module embedded in a cost-effective plastics frame instead of a metal mount using a newly developed manufacturing technology. The critical parameters of the resin, such as viscosity, are key for this process and are currently being further improved and optimized.

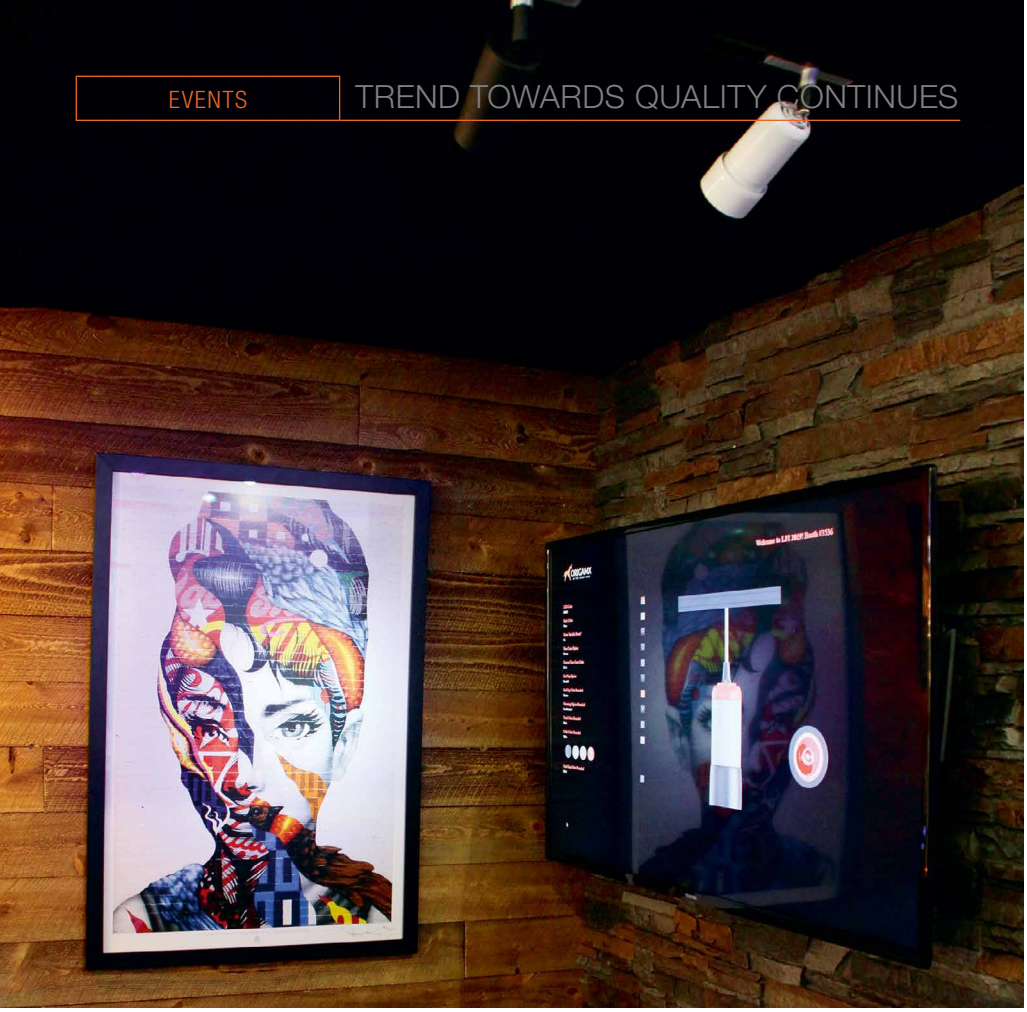
TE reported that the US market has a big interest in the recently introduced compact Zhaga compliant sensor module, which allows better design options than the original product and the NEMA compliant counterparts. On top of that, the established portfolio of LED lighting products was very well received.

▲ New production processes and newly formulated resins allow Sur-Seal to manufacture cost effective silicone optics embedded in a plastics frame

▲ Using UV-fluorescent materials, Kopp Glass demonstrated the benefits of UV-transmissive glass optics for UV LEDs



▲ With the introduction of the 40 mm diameter sensor interfaces, Zhaga compliant interfaces have started to succeed on the US market, which, up until now, has been dominated by the NEMA standard



▲ **The Black Tank's Origamx modular luminaire offers perfect light quality and a number of other unique properties**

▼ **Soraa's new dim-to-warm MR16 style spot lamps (right) required a complete redesign of their existing MR16 system**

Luminaires, systems and electronics

In a personal meeting with Signify's president for the US market, Roger Karner, we talked about the strategies of Signify for the US market and he especially emphasized the highlights on the fair. Light Fidelity is seen as a relevant technology for the future. While the current infrastructure is far from suitable for a mass application, Signify pushes the technology forward, hoping that it might become a game-changer. The award-winning Philips LED InstantFit T8 VLC for the US market is the latest example. Their second hot topic is the Interact IoT Platform. Different versions are available which are tailored for different demands.

The Black Tank is a company that, although not very well known, is actually quite remarkable. It offers a solution using LensVector technology inside. Their Origamx modular luminaire can be configured using an online configurator. Colors and shapes of the housing parts can be freely selected and combined as well as driver, LED module and optics. Especially nameworthy is their IP protected driver technology for multi-channel (tunable white and RGBW) applications, offering their "Ludicrous Mode" which allows for boosting the brightness of any CCT or color up to 4 times without sacrificing LED lifetime. Coming from the professional lighting scene, the company uses DMX and demands high standards for light quality.

Delta Electronics is often erroneously not perceived as a lighting company even though their subsidiary, ISTAR Technologies, sets new standards with their products that rely on Seoul Semiconductor's SunLike technology. But beyond that, they focus on making the life of an installer easier. Their one-for-all concept is pretty unique. The drivers accept a broad voltage range and they are able to accept almost any controls standard. 0/1-10V, DALI, TRIAC dimming, trailing or leading edge are no issue for them. Furthermore, wireless controls modules can be connected. Especially impressive are these capabilities with tunable white luminaires.

By adding a MR16 form factor tunable LCD lens, LensVector entered a new market segment. As already mentioned several brands have already integrated their interesting technology. New ideas to further increase the options and a further extension of the product line is not unrealistic. In a short discussion, Brent York, President and CEO of the company, and David Kieber, disclosed that while some of these ideas could already be performed with the current product line, they don't recommend it. The reason for that is because specific adaptations are needed to fulfill the

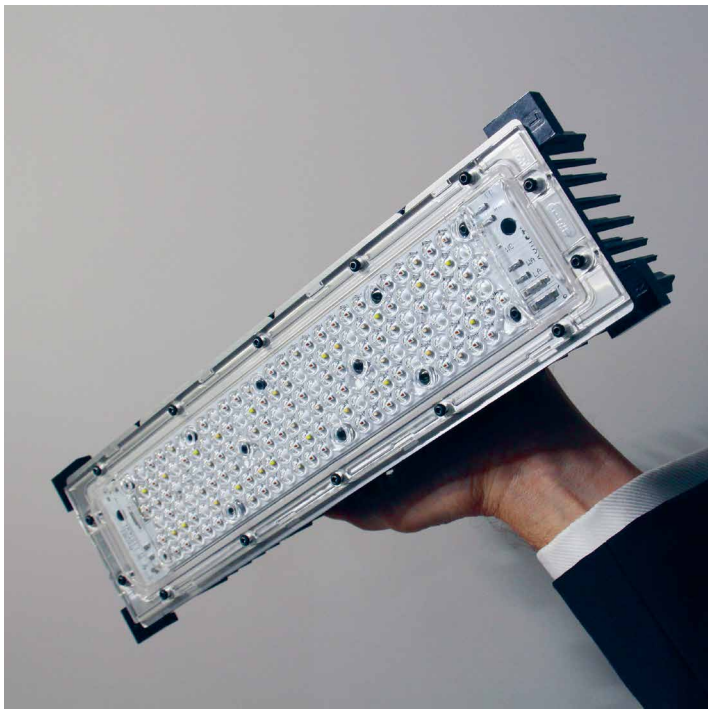
company's high-quality standards. What is more important at the moment, is the newly introduced approach that limits the zoom range to 15°-36°. While this, at the first glance, seems to be a disadvantage, it is exactly the opposite: As luminaire manufacturers can cover 80% of their applications with this zoom range, the complete system can be simplified - leading to dramatically reduced costs.

One relevant change, and a new, interesting product was the story that Soraa had to tell. Charles Selander, director of specification sales, explained that a transition from an LED lamp manufacturer to a luminaire manufacturer has just begun. Soraa will provide solutions for different available track lighting profiles and soon release their own system with magnetic mounts. To accommodate the residential and hospitality market they released an MR16 based dim-to-warm solution. The lamp is a completely new design and has just the basic chip and color conversion technology in common with their current successful MR16 product line.

Distributors and service providers

Avnet's vice president, Cary Eskow explained their strategy for supporting the lighting industry with developments and services. He identified one strength of the company in their global presence and the capability to provide the full product line in any region. One example that was shown at the booth was the horticulture module with driver and controls. While, like most industrial products, optically not spectacular, the true value and strengths lay in the details of the design, beginning with 6 channels and cautious selection of LED colors to the proper sealing of the housing to the optics and controls.

Future Lighting has already proved that the company is not just a distributor but a reliable and skilled partner for the industry to



▲ **Horticulture lighting is a growing business. Systems, like the one shown above, are offered by distributors, like AVNET. They also offer support in the design and manufacture of horticulture lights**

▲ **Another promising market is UV LED technology, especially for distributors like Future Electronics, who are experts in the field**

figure out the best solution for a specified application. In a meeting, Patrick Durand, CTO of the company, provided a flood of information on different technologies and applications. One topic, especially, caught my attention: UV LEDs; the technological progress of the last years; the prospects for the coming years; and most importantly, the possible applications in disinfection, horticulture, food processing and conservation, as well as some other applications. In this respect, most remarkable was the statement that the light source and its application is no longer the major hurdle for a broader application in practice, but rather, the materials and technologies currently used in these fields (see his commentary in this issue).

Analysis and Conclusions

The exhibition, as well as the lectures of the concurrent program, indicates that the focus of the industry currently lies on three topics.

The three major topics found:

- LED light spectrum
- IoT, artificial intelligence/machine learning & cloud-based platforms
- Modularity

A new era for human centric lighting began at the Light +Building 2016 with the introduction of TRI technology that is now the key to SSC's SunLike product range. Since then, more and more companies have recognized that the tuning of the LED's light spectrum to a more natural light has its benefits. A recent research publication from "The Society of Light and Lighting" [1] delivers the first scientific proof, and other studies with similar results will be published soon. The latest presented product lines at the show suggest that more products with similar spectral character will follow.

IoT and connectivity with all related technologies are still a big topic. In this respect, there are two points that may be the most interesting. Firstly, the technology is increasingly being used to simplify the complex process of commissioning. Secondly, in contrast to the past years where mainly luminaire manufacturers wanted to make a profit with cloud-based platforms, approaches to providing solutions for consultants and local service providers to participate in this business are increasing. Companies like ARM and Signify offer such solutions.

Some luminary manufacturers presented modular concepts. In most cases, the reason for choosing this approach was a complicated disassembly or refurbishing. Easy configuration of design as well as technical specification and lower necessary stock inventory are also important reasons. In some cases, the companies also provide an online configurator. LEDs, power specification, color or CCT tunability respectively dim-to-warm solutions, optics for different applications including zoom options, drivers and controls can be selected individually. The Black Tank and the award-winning products from Ecosense and Acuity Brands also need to be mentioned here.

In conclusion, I would say that it seems that after the enthusiasm and the resulting, not always very realistic proposals from the industry, a sense of realism has returned: Concentration on really important and probably easier to achieve goals seems to have begun to slowly prevail again. Practical value, simplicity of the solution, high quality and truly human centric solutions are written in the functional specification documents of the leading, responsible, innovative companies. ■

References:

[1] C. Cajochen et al.; Effect of Daylight LED on Visual Comfort, Melatonin, Mood, Waking Performance and Sleep, The Society of Light and Lighting – Lighting Res. Technol. 2019; 0: 1-19

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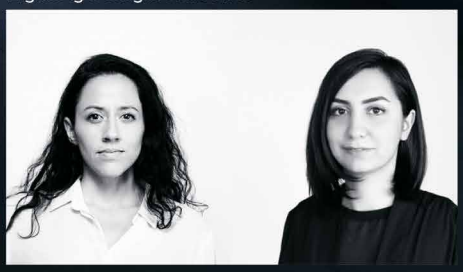

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LED Driver for High Power Machine Vision Flash

Automation is nothing new and its demands are rapidly increasing, either in production or inspection. More sensors are used and many are based on direct or reflected light detection. Some work in the visible range and others work in the non-visible spectrum of light. LED lighting has become the standard in most applications as the solid-state light source offers numerous advantages over other lighting technologies. However, the LED lighting system is only as good as the peripheral components, and LED drivers are one key element in many applications. Keith Szolusha, LED driver applications manager and Kyle Lawrence, associate applications engineer, identified the challenges for machine vision flash applications and propose a solution example with Analog Devices' LT3932 high speed LED driver.

Machine vision systems use very short flashes of intense light to produce high-speed images used in a wide variety of data processing applications. For instance, fast moving conveyor belts are run through machine vision systems for quick label and defect inspections. IR and laser LED flashes are commonly used for proximity and motion-sensing machine vision. Security systems send out high speed, hard-to-detect LED flashes to sense motion and capture and store security footage.

One challenge in all of these systems is creating the very high current and short-term (microseconds) LED camera flash waveforms, which can be spread out over long periods of time, such as 100 ms to over 1 s. Creating short, square LED flash waveforms separated by long periods of time is nontrivial. As the drive currents for the LEDs (or strings of LEDs) rise above 1 A and the LED on-times shrink to microseconds, the challenge increases. Many LED drivers with high-speed PWM capabilities may not efficiently handle long off-times and high currents for short amounts of time without degradation of the square-type waveform needed for proper high-speed image processing.

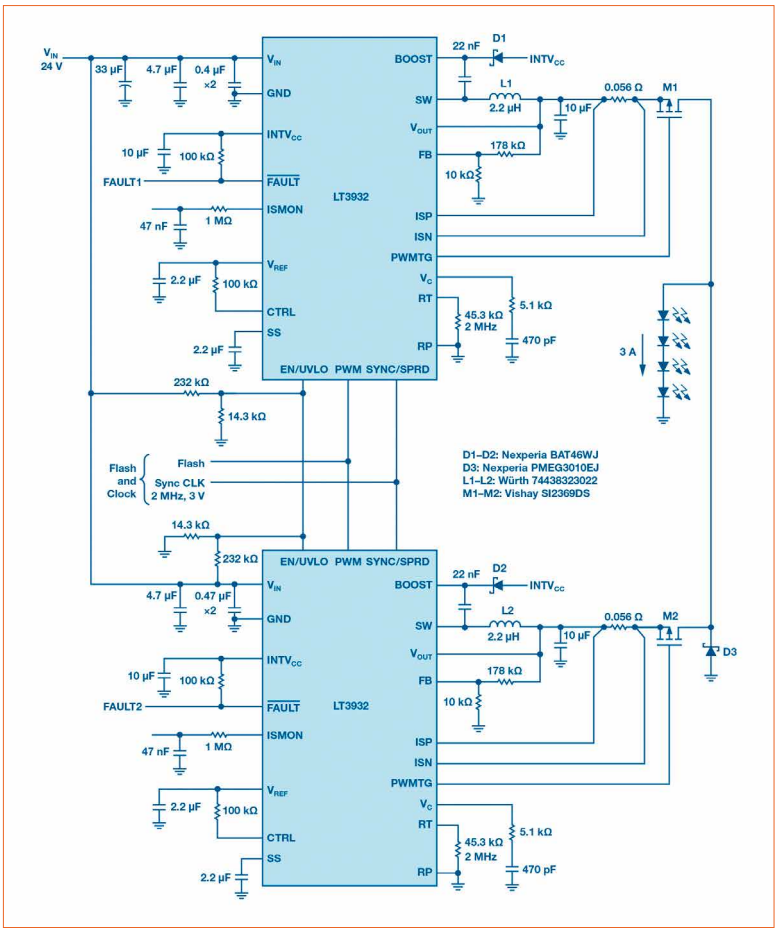


Figure 1: Parallel 1.5 A LED drivers yield 3 A machine vision LED pulses with long off-times relative to standard PWM dimming frequencies

Proprietary LED Flash

Fortunately, the high-speed LED driver in our example can provide machine vision camera flash for up to 2 A LED strings, even with long off-times of 1 second, 1 hour, 1 day, or longer. The special camera flash feature allows it to maintain the output capacitor and control loop charge state, even during long off-times. After sampling the state of the output and control loop capacitors, the driver continues to trickle-charge these components during long off-times to compensate for typical leakage currents, which is not accounted for by other LED drivers.

The proprietary flash technology scales up when drivers are paralleled for increased LED flash current. The desired flash shape and integrity are maintained. Figure 1 shows how easy it is to parallel two drivers for a 3 A camera flash - designs up to 4 A are possible.

LED flash requirements for machine vision systems are far more demanding than a standard PWM dimming driver can meet. That is, most high-end LED drivers are designed to produce PWM dimming brightness control at a PWM frequency of at least 100 Hz. This is because lower frequencies can be perceived by the human eye as an annoying flicker or strobing, even if the LED waveforms are square and repeatable. At 100 Hz, the theoretical maximum off-time is about 10 ms. During the 10 ms off-time, if designed correctly, an LED driver loses minimal output capacitor charge, allowing it to start its control loop in approximately the same state in which it ended the last PWM ON pulse. A quick response and ramp-up of the inductor current and the next LED PWM ON pulse can be quick and repeatable, with minimized start-up time. Longer off-times (for frequencies below 100 Hz) risk output capacitor charge loss due to leakage, preventing a quick response when the LED is turned back on.

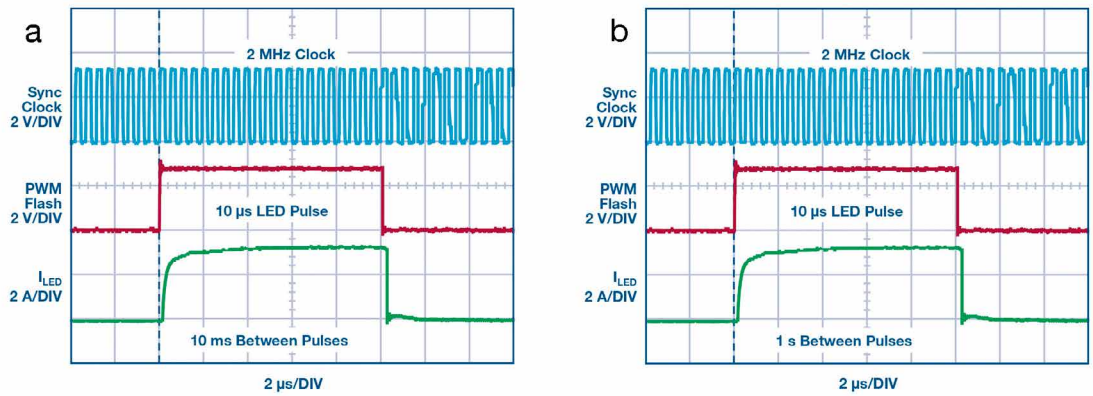
Parallel LED Drivers for Higher Current

LED drivers act as current sources, regulating the current sent out through the light emitting diodes. Since current only flows in a single direction to the output, multiple LED drivers can be placed in parallel and their currents sum through the load. Current sources do not need to be protected against current running backward through one converter or having mismatched outputs. Voltage regulators, on the other hand, are not inherently good at current sharing. If they are all trying to regulate the output voltage to a single point, and there are slight differences in their feedback networks, a regulator may draw reverse current.

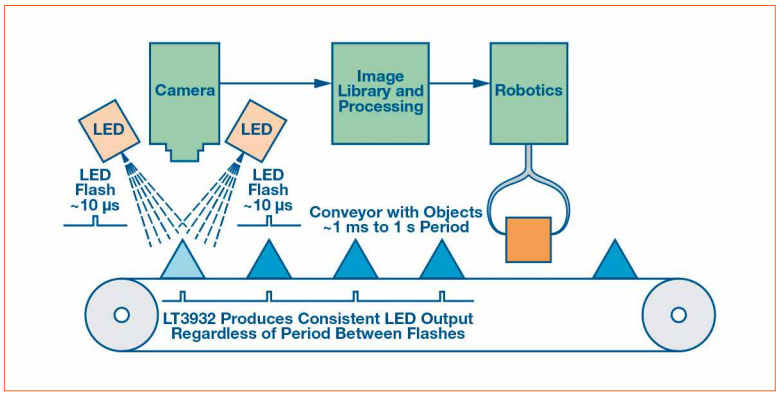
An LED driver maintains its output current, regardless of other drivers that may supply additional current summed at the output load. This makes paralleling LED drivers quite simple. For example, the LED flash system of two parallel LED drivers shown in Figure 1 efficiently drives 4 LEDs at 3 A with short 10 µs pulses spread out by long periods of time - defined by the machine vision system. Each of the converters sources half of the total string current during PWM on-time and turns off and saves its output state during PWM off-times. The off-time can be short or long, with no effect on the flash waveform repeatability.

Parallel camera flash applications share nearly the same simplicity as single converters during long off-times. The converters observe the shared output voltage at the end of the last PWM ON pulse, and keep the output capacitor charged to that state, even during long off-times. Each converter disconnects its PWM MOSFET from the shared load and keeps its output capacitor charged to approximately the last voltage state by sourcing current to that capacitor as it leaks energy. Any leakage experienced by these capacitors over long off-times is overcome by the small amount of maintenance current. When the next PWM ON pulse starts, the PWM MOSFETs of each converter are turned on and the output capacitors start up in approximately the same state as the last pulse, regardless of whether 10 ms or a full day has passed.

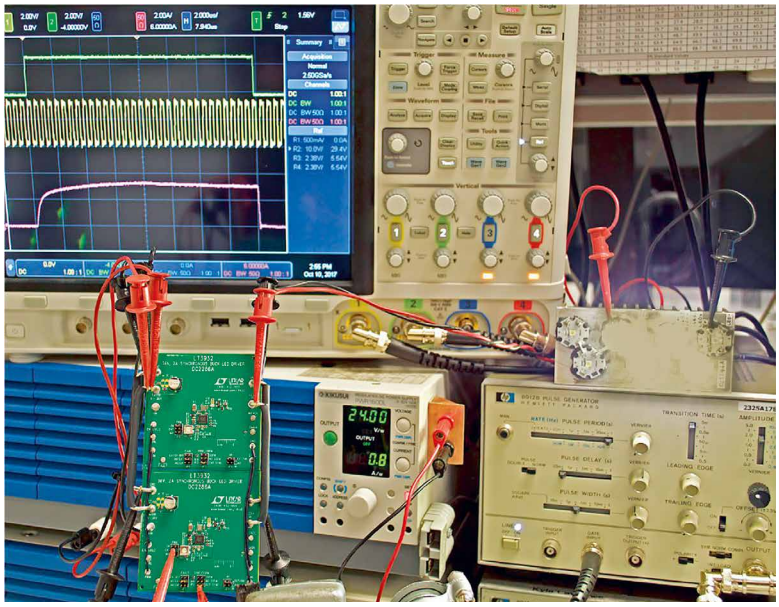
Figures 2a&b demonstrate the parallel LED drivers driving 4 LEDs at 3 A with a 10 µs machine vision camera pulse. The LED pulse is sharp and fast, regardless of whether there is a 10 ms PWM



Figures 2a&b:
3 A camera flash waveform of Figure 1's parallel LED drivers looks the same regardless of the amount of PWM off-time. Waveforms show that a 10 µs pulse after (a) 10 ms and after (b) one second are the same. This LED flash also looks the same after a day or longer of PWM off-time



Figures 3:
An example of machine vision on an industrial conveyor belt. Inspection systems move at many different speeds, yet the flash technology must be fast and crisp



Figures 4:
Two demo circuits are easily connected in parallel to create the 3 A to 4 A machine vision LED flash application shown in figure 1

off-time (100 Hz) or a 1 s PWM off-time (1 Hz), which is ideal for machine vision systems.

Even Higher Current Is Possible

Parallel LED drivers are not limited to two converters. Three or more converters can be paralleled to create even higher current waveforms with sharp edges. Since this system does not have a master or slave device, all of the converters source the same amount of current and share the load equally. It is recommended that all of the parallel LED driver converters share the same synchronized clock and remain in-phase. This ensures that all converters have approximately the same phasing on the ripple of their output capacitors so that ripple currents do not flow backward or between the different converters. It is important for the PWM pulse waveform to remain in-phase with the 2 MHz synchronization clock. This ensures that the LED flash waveform remains square and without jitter, producing the best image processing results.

The demonstration circuit is designed to drive 1 A of LED current through one or two LEDs as a step-down LED driver. It can easily be altered and paralleled, as shown in Figure 1, for higher current, higher voltage, or parallel operation. Figure 4 demonstrates how two of these circuits are easily connected together to drive 10 µs, 3 A pulses through 4 LEDs from 24 V input. For testing purposes, a pulse generator can be used for the synchronized clock signal, as shown in Figure 4. In a production machine vision system, a clock chip can be used to generate the synchronized sync and PWM pulses. For higher current pulses, add more demonstration circuit converters using the same parallel scheme.

Conclusion

Machine vision systems can use parallel LED drivers to create the fast, square, high current waveforms required for automated image processing. The selected LED driver's proprietary camera flash technology can be extended to higher currents by connecting parallel converters. As a result, 3 A and higher pulses on the order of microseconds are possible, even with long off-times. LED camera flash waveforms remain square and without jitter, no matter how long the off-time between LED flashes may be. This is a requisite for safe and reliable operation of machine vision system applications in production. ■

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Transparent Material Considerations for UV Optics in Horticultural Lighting Applications

Advancements in UV LED technology have begun changing the horticultural lighting landscape. Research is still ongoing to discover the extent of benefits and best practices of using UV light in horticulture. Using optics in tandem with UV LED light systems can help reach performance goals and optimize growing. Although there are several UV- transmitting materials available, not all are equivalent or able to meet the requirements for UV applications. Justine Galbraith, glass engineer, and Sharayah Follett, market development manager at Kopp Glass, Inc. discuss the performance considerations of various UV-transmitting materials and how application challenges are addressed by integrating optical elements.

The advancements of LEDs enable simultaneous light intensity and spectrum control, resulting in a more efficient and productive method of providing light for plant growth than traditional sources. This is further realized by improvements made in UV LEDs, allowing growers to integrate specific doses of targeted UV wavelengths at the right time of a harvest cycle to increase the quality of plant growth in a more cost-effective manner.

Though the technology is continually progressing, commercially available UV LEDs still have limitations in achieving performance goals in horticultural applications. Using UV LED array design and corresponding beam angles alone, it can be difficult to maintain or extend working distances, maximize light intensity, and ensure uniform light coverage on the plant canopy.

Traditionally, optics have been used to address these limitations and control the light output of the fixture. However, designing an optic to enhance the performance of UV LEDs, especially at lower UV-B wavelengths, brings an entirely new set of challenges for those experienced in traditional technologies. Not all materials transmit the required UV wavelengths, and not all UV-transmitting materials perform equivalently in application.

Benefits of LEDs in Horticultural Applications

LEDs have many benefits over the legacy technologies of incandescent, fluorescent, high-intensity discharge (HID) or high-pressure sodium vapor (HPS) lights that have historically been used in indoor farming operations.

One major benefit of using LEDs in horticultural settings is temperature control. HPS bulbs produce a broadband spectrum that includes near-infrared light, which accounts for much of the heat generation. For LEDs, most of the energy input is converted to light. Some energy is lost to heat, but it is managed through heat sinks, water cooling, and other techniques. LEDs allow growers to better manage the environmental temperatures needed for specific plants.

LEDs are generally more energy efficient. For the same amount of light output, LEDs typically use

much less energy than legacy bulbs. LEDs also have much longer lifespans, sometimes reaching over ten years. This all translates to lowered costs of ownership for growers [1].

Finally, LEDs offer targeted wavelength emission ranges. With tunable spectrums, the user chooses the optimal wavelengths depending on the application or needs of the species being cultivated. Most commercially available LED lighting fixtures have combinations of red, green, blue, and/or white LEDs that can be tailored based on the desired effect, such as flowering or vegetative plant growth. However, UV light has been shown to bring additional benefits for horticultural applications.

Benefits of UV Radiation on Plant Growth

Research into the effect of UV radiation on crops has been ongoing since the 1960s. With the advancement of UV LEDs, researchers now have low-heat light sources with narrow emission bands in the UV region. This has enabled the evaluation of targeted wavelength ranges; for example, recent testing found that UV-B (280-315 nm) radiation "increases photosynthetic rate, provides photoprotection to young seedlings prior to being transferred to the field, and improves pigmentation, aroma, and resistance to fungal diseases and insects" [2].

UV light targets plant photoreceptors and regulates secondary growth processes throughout plant life. This has been shown to enhance flavor, texture, and appearance of plants. In one study, NUV-B exposure caused both lettuce leaf thickness and poinsettia branching to increase [3].UV light can also improve disease resistance as well as increase shelf life. It has been shown to reduce mold and mildew. For example, cucumber lesions have been shown to decrease with UV-B exposure [3].

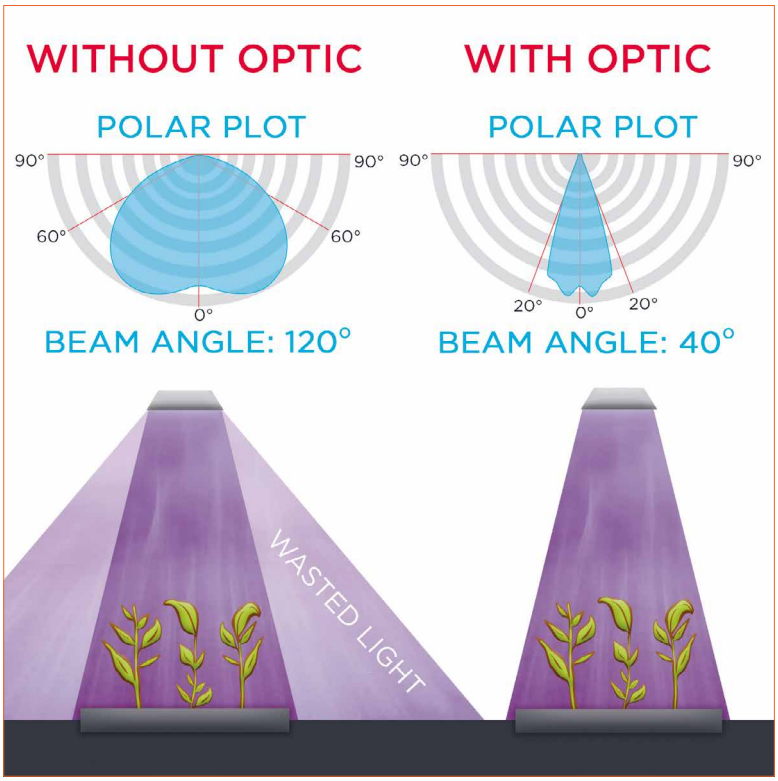

Figure 1: Simulated UV LED system without an optic in application is compared with a system with an optic. On the left, the result of a wide viewing angle is wasted light. On the right, light is effectively directed toward the plant canopy

It is important to keep in mind that the UV light dosage and required wavelengths are crop dependent. Timing and placement of the UV light into the grow cycle should be chosen carefully per species and desired results, with an understanding that excessive power and exposure to UV rays can be detrimenta.

Considerations for Integrating UV LEDs into Horticulture

A key challenge when implementing this technology is determining how to integrate UV light fixtures into existing grow operations or infrastructure.

Visible light fixtures are typically more than four feet away from the plant canopy. This working distance provides ample room for plant care and maintenance. This distance is particularly relevant in vegetative and flowering stages for taller plant species, as well as in greenhouse applications where supplemental lighting fixtures can be more than fifteen feet away from the target surface.

At these working distances, it can be difficult to integrate UV LEDs, especially those emitting in lower wavelengths (UV-B). This is because most commercially available UV LEDs have wide beam angles, typically 120-140 degrees, and lower power outputs compared to visible LEDs. As the working distance is increased, the coverage area from the LEDs also increases and can quickly become larger than standard plant canopies. This results in wasted light limiting both the efficiency of the system as well as the ability to achieve the optimal dosage and photon flux density (PFD) required for plant growth. The left of figure 1 demonstrates the wide viewing angle of an LED without an optic and the result of wasted light in application.

One method of addressing this challenge is bringing the fixture closer to the plant canopy to ensure that all of the light from the UV LEDs is directed onto the target surface. This may require a significant re-design of infrastructure, which can be cost-prohibitive and interfere with the space necessary for grow operations. Another solution is increasing the number of LEDs to achieve the target PFD. However, this can also be cost-prohibitive and does not address wasted light and optical inefficiencies.

For lighting fixtures using visible LEDs, a common solution is introducing a collimating optic to achieve a specified beam angle. In this way, working distance can be extended while ensuring that energy is not wasted on light missing the intended surface, and that the target power amount is maintained. The right of figure 1 demonstrates the impact of an optic on viewing angle and the effect in application to direct and capture stray light. By controlling the beam angle of an LED, the design flexibility necessary to overcome extended working distance is made possible.

However, this solution is not as straightforward for lighting fixtures using UV LEDs. This is due to the limited availability of transparent materials suited for UV optics in horticulture. Material requirements include high transmission at critical UV wavelengths, mechanical durability to maintain optical properties in the horticulture operating environment, manufacturability into desired shapes and sizes, and finally corresponding price.

Determining the expected performance and lifetime of different UV-transmitting materials requires the consideration of both critical material properties and operating environment.

While this article focuses on UV light, it is important to select a transparent material that can transmit visible and IR wavelengths, allowing for the design and realization of full spectrum lighting products.

Transparent Materials for UV Optics

A common misconception is that quartz is the only transparent material able to withstand prolonged exposure at lower UV wavelengths. However, new material advancements, such as Kopp's development of a specially formulated, UV glass, enables optics to be manufactured that have high transmission across UV, visible and IR wavelengths and can withstand demanding operating environments.

The three main categories of transparent materials that can be used for optics in UV applications are polymers like acrylic and silicone, ceramics and glasses like quartz and fused silica, and specialized UV glass compositions. It is important to note that UV glass is not a standard material offering due to compositional design, development, manufacturing restrictions, and cost considerations.

When selecting a transparent material for UV optics, there is no one-size-fits-all solution. Each material has unique properties that dictate the control of light. It is vital to evaluate each material property with all aspects of the lighting system in mind – from the operating environment to the desired light output performance goals for the application.

For horticultural applications, the criteria to consider include transmission, thermal properties, lifetime of material, optical efficiency and most significantly, flexibility in manufacturing the required optical design. Essential properties are summarized in table 1 and

Table 1:
Important material properties to consider when selecting a UV-transmitting material for an optic

Property	Definition	Impact in Application
Absorption, Transmission, and Reflection	Absorption is the reduction of light as it travels through a material. Conversely, transmission is the amount of light that makes it through. Reflection for transparent materials usually occurs at the surface and is a function of wavelength and index of refraction.	These properties—along with design—help to determine the light output of an optic.
Thermal Resistance	The operating temperature of optical material needs to match the operating temperature of the UV LED. UV LEDs should be thermally managed to reduce operating temperature to maintain lifetime, efficiency and output.	If the material is heated above its maximum operating temperature, this can cause the optic to deform.
UV Stability	Depending on the composition of the material and the quality of the light, transmission may not be stable at certain UV wavelengths. This property is generally healable once exposure stops. UV radiation can also affect the structural integrity of materials in the form of yellowing or breakage on the surface.	Materials that are not stable under UV exposure can either lose transmission, become damaged, or both. This causes the light output to degrade.
Chemical Resistance	Whether the material is exposed to something as common as water or other harsh chemicals, it is vital to know how the material will perform. Chemical resistance depends on the composition of the material.	Surface degradation, as a result of exposure to humidity and harsh chemicals, affects transmission.
Refractive Index	The index of refraction determines how much light is reflected and transmitted at the interface and the angle at which it is refracted. This value is unique per material.	This property is needed by the optical engineer to optimize the optic design to meet performance goals.
Hardness and Rigidity	Hardness is the ability of a material to resist being scratched, fractured, or permanently deformed by sharp edges of another material. If the hardness of a material is known, one gets a sense of its resistance to abrasion. Rigidity, also known as stiffness, is the extent to which a material can be bent or forced out of shape.	Soft materials are at risk of becoming abraded at the surface affecting transmission. Lack of rigidity may mean the part can move, which can negatively affect light output.

discussed in the following sections to detail the impact in application.

Transmission of Transparent Materials

Transmission is the first level of consideration when selecting a UV-transmitting material. It is necessary to identify the wavelength of interest and then determine whether a material will transmit enough light to be an appropriate fit for application. Figure 2 compares the transmission spectra of the above-mentioned materials at UV wavelengths.

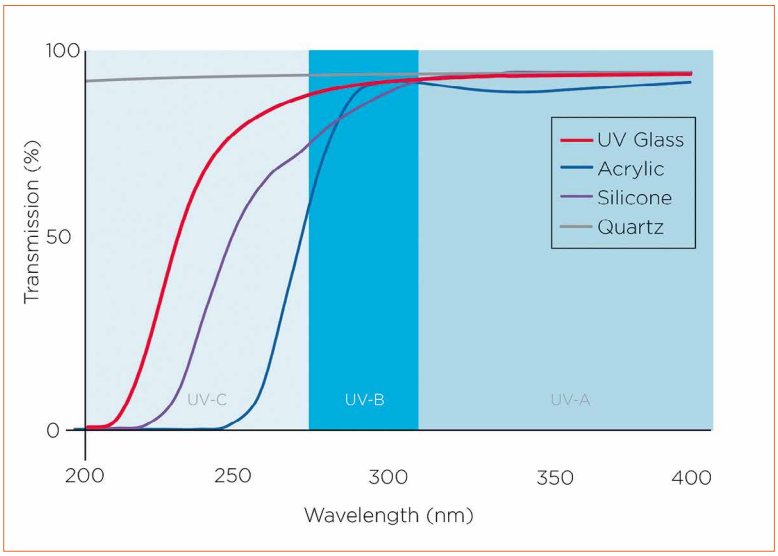

Figure 2: **Transmission of transparent materials at UV wavelengths**

Optical design is essential

An optimized optical design will direct all possible light onto the target surface and can increase the optical efficiency of a system. In many cases, optics made from materials with lower transmission will result in more light reaching the target plant canopy compared to a flat window with higher transmission but no optical features.

Industries that utilize LEDs have a history of using quartz for windows and simple optics like rods. While quartz has favorable transmission, it has material and manufacturing limitations that make optical designs difficult to manufacture. Unlike quartz, specialized UV glasses that are designed with the end application in mind, can be manufactured into complex and contoured shapes without fabrication. This flexibility allows optical features to be molded into both the incident and exiting surfaces of the optic.

Optical design will be discussed in detail later, but it is important to keep in mind throughout the process of evaluating transparent materials.

Thermal Considerations

As noted above, a key benefit of LEDs in horticultural lighting applications is that they have lower heat outputs and operating temperatures compared to traditional light sources. LEDs do produce some heat; however, the heat is generated due to inefficiencies in the conversion of electrical power to light, rather than by IR radiation.

UV LEDs tend to run hotter than visible LEDs because they have lower wall plug efficiencies. The optical power of UV LEDs accounts for 15-25% of the input electrical power whereas visible LEDs have closer to 40% efficiency in generating light [4] and the higher the power of the LED, the more heat can be produced.

In most cases, LEDs will be thermally managed, usually through air or water-cooling. However, it is necessary to know the operating temperature to select an optical material that will not degrade or deform at that operating temperature.

Effect of Application Environment on Lifetime

It is imperative to keep in mind how the optic will be impacted by exposure to varied operating conditions in the application environment. For example, a material such as UV glass is highly resistant to abrasive conditions, heat cycling and UV radiation exposure, whereas plastics in the same environment will erode and discolor resulting in severe transmission loss. It is important to note that a loss in transmission can significantly affect the performance of a light fixture, especially in applications like horticultural lighting where consistent and uniform light output are required.

Additionally, the influence of application environment on the fixture itself should be considered. UV LEDs, especially in the UV-B region, are still relatively expensive and their performance can be significantly impaired by exposure to water and humidity. Flat windows, cover lenses, and optics are commonly used in visible lighting fixtures to protect internal components against environmental exposure and to achieve industry certifications. These include IP ratings and certification marks such as UL, ETL, CSA, and CE. Similarly, UV-transmitting windows and optics can be used to protect UV LEDs.

To ensure UV LED systems continue to function properly and that the elements are adequately protected, it is essential to use a durable material that will not lose transmission over time or degrade after prolonged use.

Material stability under UV exposure

The optical stability - or the ability for a material to maintain transmission during use - depends on both the light source parameters, like wavelength and optical power,

as well as the type of material used. In many instances, prolonged UV exposure can decrease the transmission of a material. This characteristic differs from material to material depending on its chemical composition, design, and processing. Some materials will be much more stable than others. As such, material manufacturers should be consulted regarding UV transmission stability.

It is also important that the structural integrity of the material remain intact after prolonged UV exposure, especially in horticultural lighting applications using UV-B and UV-C wavelengths. When exposed to UV light, quartz and UV glasses are mechanically stable. On the other hand, most polymers, such as acrylic, will degrade and become destroyed at the surface when exposed to UV radiation, even for a short time [5].

Chemical resistance in operating environment

Often, horticultural lighting fixtures are exposed to water, humidity, and other chemicals used in application. Some, such as hydrogen peroxide, can leave a film on the lens that reduces transmission. If the material cannot withstand the environment, its performance will degrade, negatively affecting the growth of plants. Additionally, an easily cleaned and maintained material is ideal.

Quartz and specialized UV glass can both withstand humid environments and are resistant to various chemicals. Polymers are much less resilient to humidity and chemical exposure; they are at a higher risk of degradation, which impairs transmission and efficacy.

Material Selection Impact on Optical Design

As a final step, how the material will be transformed into its final shape as an optic should be considered. Material parameters, such as index of refraction and manufacturability, will determine what optical designs are realistic. The optical design itself and the inherent transmission of the material selection will determine the system's optical efficiency as well as the eventual light output.

Index of refraction

The index of refraction indicates how fast light travels through a material and how it is reflected and refracted at interfaces. This material property is dispersive, so it should be determined for the wavelength of light used in application.

Every material has a critical angle, which is determined by its refractive index. If incident light hits a surface at angles above the critical angle, it will be fully reflected with no transmission. Figure 3 shows an example of total internal reflection (TIR) and how this principle is used in optical design. These angles are fundamental for designing curvatures of optics to achieve design goals. Both material transmission and index of refraction should be known at the onset of the optical design process. Since different materials have different indices of refraction, substituting materials requires redesigning the optic.

Ensuring material manufacturability

To achieve performance goals, the transparent material must be able to take the shape of the optical design. Therefore, manufacturability is a critical characteristic of the transparent material.

Industries that utilize LEDs have a history of using quartz for windows and simple optics like rods. While quartz has favorable transmission, it has material limitations making optical designs difficult to manufacture. It cannot be molded or pressed into complex shapes. Fabrication techniques for this material are also limited. This drives up the cost, making the material impractical.

Polymers are equally as impractical, but for the opposite reason. Polymers can be molded into complex shapes but, due to limitations in processing methods, size is limited. Many compositions lack chemical resistance and will degrade after prolonged UV exposure, negatively impacting performance in horticultural applications. Polymers also lack rigidity, meaning they can bend, whereas glass and quartz are stable. This can allow for an optic to become unaligned from the UV LED array and result in light output variability.

Specialized UV glass compositions, such as Kopp's UV offering, are designed to achieve performance goals. This includes transmission of critical UV wavelengths, material durability and the opportunity to manufacture complex optical shapes in a cost-effective manner through molding processes. The flexibility in compositional design and manufacturability ensures the optic can meet the needs of an application or operating environment.

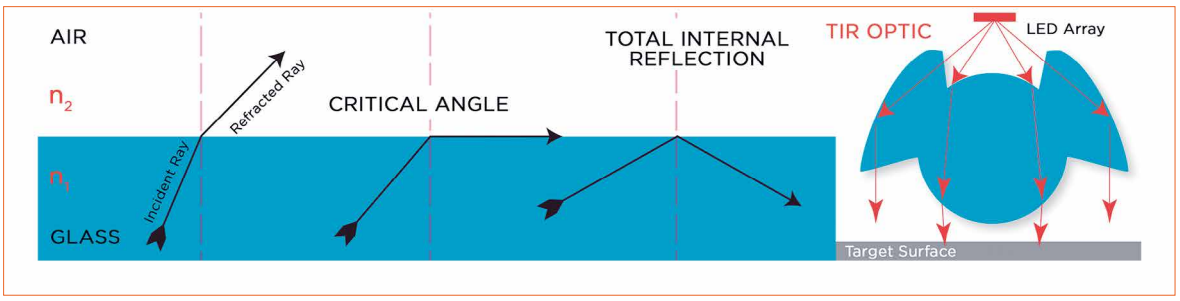

Figure 3: Example of total internal reflection (TIR) and how this principle is applied in optical design

Optical design process

The final consideration in material selection is to evaluate how optical design will impact the output of the lighting fixture. When manufactured from the best-suited material, the optic will effectively achieve the performance goals of the end user. For example, an optic can be designed to extend the working distance of the lighting fixture while maintaining light output. It can re-direct UV light to provide uniform light coverage on a plant canopy with a large footprint. It can collimate light to ensure even coverage as the plant grows taller. Or it can achieve all the above as performance goals are varied and driven by the application or end user.

The optical design process typically begins with an optical engineer. They will need to know the parameters of the UV LED (manufacturer, spectral distribution, peak wavelength, beam angle), the optical properties of the material (transmission, refractive index) and the desired performance goals (beam angle, PFD map, irradiance map). The engineer uses this information to determine the type of optic that will optimize the system to achieve optical targets. Figure 4 is an example of a UV glass optic designed to enhance a linear array of ten UV LEDs.

To produce an optic that is optimized for both manufacturing and light output, the optical engineer, optic manufacturer and lighting OEM must collaborate early in the design process. Without working together, the optical engineer may design an optic that produces an ideal light distribution within the lighting OEMs fixture constraints that is not aligned with the optic manufacturer's capabilities. As a result, the design could be more costly or even impossible to produce without modifications. Early collaboration reduces time spent in product development, prevents costly re-designs, increases manufacturing yields and accelerates time to market.

Figure 4:
UV glass optic optimized for a linear array of 10 UV LEDs

Conclusion: Optimize UV LED Performance with UV Glass Optics

Optics benefit and enable the development of differentiated and efficient horticultural lighting fixtures. They allow for design flexibility to overcome application challenges and achieve performance goals. Optics can be paired with both visible and UV LEDs; however, at UV wavelengths, additional consideration needs to be taken to select an appropriate optical material.

When designing an optic for UV LED lighting systems, it is vital to select a material that transmits the appropriate amount of UV light at the critical wavelengths, exhibits durability and maintains output in the horticultural operating environment. The material must also be manufacturable into complex shapes and sizes in a manner that is not cost-prohibitive.

UV glass optics are able to meet the performance and manufacturability requirements of horticultural applications. They improve fixture optical efficiency by effectively directing light to the target surface, providing optimal coverage for the plant canopy, enabling working distance control, and protecting the internal components from the operating environment.

The implementation of UV glass optics allows for growers to realize the benefits of UV LEDs including, enhanced quality of product, increased yield as well as lower energy, operating and maintenance costs, resulting in more productive and profitable grow operations. ■

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Growing Crops Under the Best Possible Conditions

Within the last years, horticulture lighting has become an increasingly important topic for LED manufacturers and the whole lighting industry. However, there is still uncertainty about the benefits and best practice. Questions like, "Is it cost effective?" or "How can it be applied cost effective?" or "How complex must a system be?" or "what else is possible today?" make customers insecure when they make decisions. Arjan Kok, Bosman Van Zaal, from Smart Greenhouses and Bram Meulblok, formally of BLV Horticulture Lighting, now with Ophir, an MKS brand, explain the different greenhouse types, their requirements and the current options and approaches.

The horticulture field covers the art and science of growing plants for various reasons. This means growing fruits, nuts, vegetables, herbs, flowers, foliage plants, woody ornamentals, trees, or even growing plants for soil improvement.

Plants are grown in various ways:

- Grains, vegetables and other crops in field production
- Fruits and nuts in orchards
- Algae cultivation in tanks or tubes

However, not all locations are suitable for growing crops and we are growing crops in very harsh environments like the Arctic and Antarctic, or even the moon, for that matter.

For this article the authors will narrow it down to the most advanced forms of horticulture, the growth of crops in greenhouses and indoor farms.

Introduction

A constant, ideal climate

The growing demand for year-round food and crops is increasing. Consumers demand fresh fruits and vegetables even in winter. But not every environment and every climate allows for growing crops all year round. That's why it's important to create the ideal growing climate indoors.

There are two ways to grow crops indoor, sheltered from the less ideal outdoor conditions:

- A greenhouse, which still uses sunlight
- Climate chambers, mostly called vertical farms, which are completely enclosed environments

Currently, innovation in horticulture is led by The Netherlands, with the largest number of greenhouse builders, crop specialists, climate computer manufacturers, lighting manufacturers and other related specialists.

It is only logical that the introduction of new technologies would start in a small country with a large population, high salaries and high prices for land and a need for optimization. The US and Canada are, however, catching up with their high-tech Cannabis cultivation.

Reasons to introduce new technologies in greenhouses

The main reason to grow crops indoors is because the outdoor climate is not suitable for the crop you want to grow. But there are more reasons for introducing technologies into cultivation. These reasons are based on four significant pillars.

The four significant pillars:

- Optimizing production
  - Quantity (yield)
  - Quality
- Reducing threads
  - Whether extremes
  - Bugs
  - Diseases
- Reducing costs
  - Labor
  - Resources: optimizing the use of (natural) resources the plant needs to grow, minimizing the run-off:
    Water
    Nutrients
    Heat
    Light
    CO_2
- Food safety

Greenhouses

A greenhouse makes it possible to grow all year round and technically there are almost no restrictions anymore for harvesting 80-90 kg/m^2

of tomatoes. The production numbers directly relate to the investments made in the various technical systems, quality of the starting plant material (1 Kg of high-quality seeds is 2.5 times more expensive than 1 Kg of gold) and the level of grow management that the crop 24/7 gets. Also, the distribution of the harvested production is a big part of the Business Case of each nursery. Making a comparison in this case is not a simple calculation; it's a matter of configuration.

Figure 1:
Before a seed is able to grow, there are a few main elements to be organized.

Greenhouse construction

Bosman Van Zaal has close to a century of experience as a greenhouse builder and installer of associated systems. They have the knowledge to realize the ideal construction for every type of crop, where natural conditions are hardly an obstacle. Circumstances like light and climate fulfill an important role in the process of every nursery: controlled photosynthesis.
There are several greenhouse construction types available with each specific property.

Figure 2:
Example for a Venlo style greenhouse

In general, there are 3 types:

- Venlo style greenhouses
- Wide span greenhouses
- Foil greenhouses (Multi span)

These types all have their own benefits and limitations and all use different ventilation systems and screen installations. The choice of greenhouse depends on the location of the greenhouse, the crop and the budget of the grower.

Figure 3:
Example for a wide span greenhouse

Climate systems

Climate plays an important role in the production and quality of crops and the desire to grow year-round. In order to create the ideal environment, care must be taken for the perfect, constant mix of heating, cooling, light, CO2 and moisture content, regardless of extreme (outdoor) climatic conditions. Moreover, these production facilities should be energy saving.
For example, Bosman Van Zaal realized the first "greenhouse without

Figure 4:
Example for a foil greenhouse (multi span)

Figure 5:
Research facility in Germany with cooling and heating capabilities per test cell

Figure 6:
Single pot transport system

Figure 7:
Robot operated table transport system

gas-connection", in collaboration with Wageningen University.

Water systems

To supply plants with water and nutrients, installations are used that are regulated according to the cultivation recipe. In general, sustainable irrigation and fertilization systems are used and all residual flows are reused or controlled. These systems are linked to software that allows direct insight in consumption and need of the crop depending on its growth phase.

Logistical cultivation systems

Logistical cultivation systems have become so evolved that the development has been elevated to a form of art. Bosman Van Zaal is well known for their high level of logistical cultivation systems. A greenhouse can use anything from manually mechanized systems to fully automated robotic solutions, including mechanical or electrical control and software.

These systems are focused on labor productivity, space utilization, tracking & tracing and cost control. In particular, in the automation and robotization of harvesting and processing activities, Bosman Van Zaal uses the expertise of their sister company Crea-Tech.

Control systems & software

It is important that the growers can rely on an accurate operation of the system in which constant quality, usability and low costs are paramount.

The three most advanced brands are Ridder (HortiMAX), Hoogendoorn and Priva.

Electrical systems

Electricity is the basis of the drive and control of all the systems. This is why electrical systems play a central role in the activities related to the operation of a greenhouse. Electrical systems for the drive of the irrigation systems, ventilators, logistical cultivation systems, roof openers, light installations and many more, are needed. Sustainable and efficient energy management is a big priority. Electrical installations are mainly based on high voltage installation, for the most part, around 400 V and 50 Hz (480 in the USA, 600 V in Canada). These installations mostly use 5 core cables, so they can use three phases that nicely balance out the electrical load and can use a ground and a zero to also be able to connect low voltage appliances (230 V, 50 Hz).

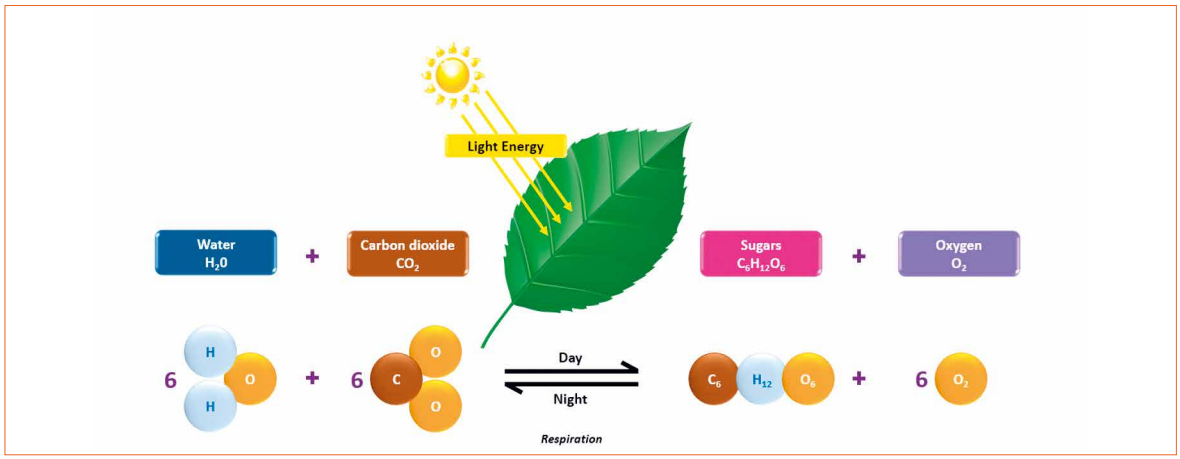


Figure 8:
Process of photosysthesis

Light Used for Crop Cultivation

In connection with the electrical installation comes the lighting installation. Light is a crucial component in the growth of crops as it induces photosynthesis (water and CO_2 are under the influence of light transformed into sugar and oxygen. The plant uses the sugar to grow and produce leaves, flowers and fruits.

In greenhouses different light sources are used, which we will cover in more detail:

- Sun
- HPS (High Pressure Sodium)
- MH (Metal Halide)
- LED

Of course sunlight is the most important one. Almost all the field production and for many low-tech greenhouses in the world it is the only source of light, but what about the more high tech growth facilities?

In greenhouses people have used artificial light since the 1950's and started using it in Scandinavia. Growers have always been looking at the most efficient light sources, since the artificial lighting uses a lot of energy (for roses it is calculated that the artificial lighting cost between € 25 and € 35 per m^2). Growers use the artificial light up to 5,000 hours per year for the high value flower, Lisianthus, growth. Also roses and chrysanthemum need a lot of light. For vegetable growth people use artificial light in tomato, cucumber, and pepper cultivation.

We have to bear in mind that plants do not "see" light as we do. Humans are very sensitive to green/yellow light (555 nm), plants are most sensitive to orange/red light (633 nm).

Plants also do not see the difference in energy in light. A photon of 400 nm blue light carries 1,75 times more energy than 700 nm red light, but the plant just "sees" it as a photon, which activates the photosynthesis.

This is also why in 2004 people decided to use µmol/m^2 instead of Lux as a value for the light level in plant growth.

Sunlight

Growers see sunlight as the free light source and greenhouses are built in a way that it collects as much sunlight as possible. Sunlight, however, is not a constant. We have more sunlight in summer, both in hours and intensity and the light level also varies throughout the day. But light level is not the only thing that changes; light color changes as well. In the morning and the evening, we have "warmer" light colors with a higher percentage of red and far-red light. In winter, percentage wise, we receive less blue light during a day.

It is interesting that light not only influences growth, or photosynthesis, but it also influences photomorphogenesis. The thing that makes that interesting is that photomorphogenesis influences shape, plant length (or stretching), lycopene content and flower induction (in various types of plants).

Plant shape

Plant shape is important in ornamental plants, which are bought for their looks. For example, we like our pot plants to be nice and compact, with a high density of branches and flowers in a relatively small plant. Plant shape, however, also influences whether a plant is more or less susceptible to diseases, because a more compact plant has a thicker cell-wall and the physical boundary is the only real

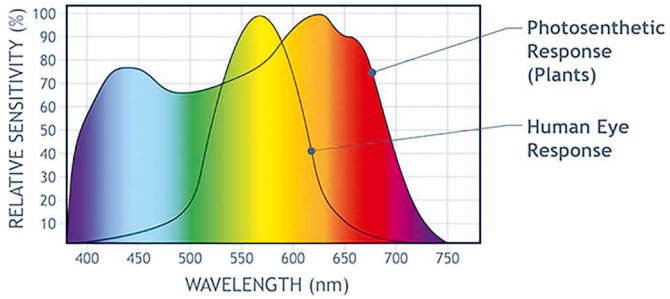


Figure 9:
Light sensitivity across wavelength for plants versus humans

Figure 10:
HPS spectrum (left), MH spectrum (center) and 1000W HPS fixtures with open reflector design (right)

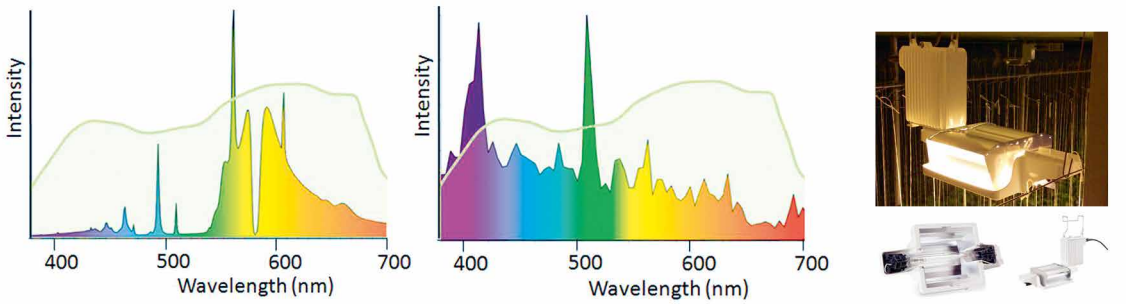
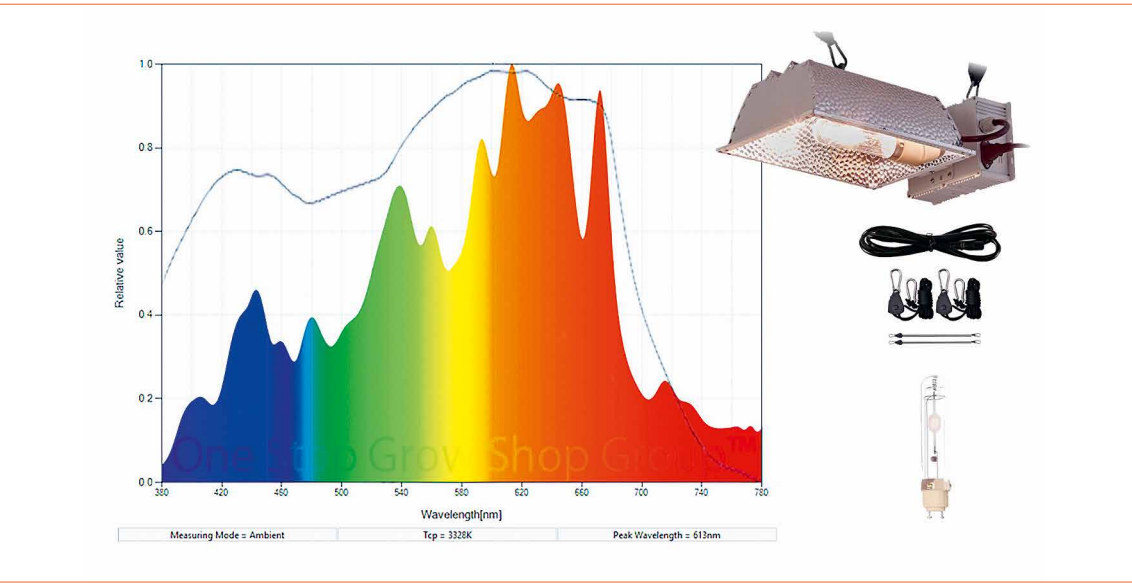


Figure 11:
CMH spectrum and CMH fixture and lamp



defense. Plant shape also has an influence on whether a plant grows thick thorns or not, which means its fruits are harder to harvest.

Plant length

Plant length influences how far apart branches are and this has an influence on whether there is enough room for fruits to grow in-between internodes (branch clusters). It also influences stem length in stem roses, or other cut flowers.

Lycopene content

Lycopene content influences taste, smell and the amount of nutrients, which is very important in vegetable, fruit and herb production. It is also very important in the pharmaceutical industry where a medicine's efficiency depends on a certain ingredient. The easiest example that most people know is the THC level in Cannabis.

Lights for Greenhouses

Now that we know what light can do, we can also look at which lights are used in greenhouses and why.

In the beginning people started using Mercury lamps as the light coming from this type of lamp was very close to sunlight and it had relatively high efficiency. Later when people found out that plants actually react best to red light they changed to HPS lamps, which were also even more energy efficient.

High pressure sodium (HPS)

HPS is still the light source that is used the most in greenhouse cultivation. The most modern versions of these discharge lamps are the 1 kW fixtures with double-ended lamps.

(Ceramic) metal halide

Metal Halide (MH), or Ceramic Metal Halide (CMH) are used when more blue light is needed for more vegetative growth, to keep the plant more compact and slow down the fruit producing intent of the plant. This makes the plant stronger. It also means that later in the production cycle it can better handle the fruit load and that the plant is less vulnerable to diseases. MH and CMH are also discharge lamps.

An added benefit from discharge lamps is that they have a lot of radiated heat (infra-red) and very little conductive heat. The radiated heat raises the leaf temperature by 2-3 degrees, which means that with high humidity the moisture will never get on the leaves, but will always get on the glass and aluminum, and that means the stomata in the leaves can open and can catch CO_2 needed for photosynthesis.

HPS is 10% more efficient than MH. The efficacy of HPS is 2,1 µmol/s, CMH and 1000 W MH have an efficacy of 1,9 µmol/s.

LED in greenhouses

LED's are slowly making their way into greenhouses, but for a lot of growers it is not yet a real business case. LED's are, on average, about 30% more efficient than HPS, but this highly depends on the spectrum used. A very good white light spectrum might only have an efficacy of 1.7 µmol/s, where a 90%red and 10% blue spectrum could have an efficacy of up to 3.0 µmol/s.

Why is it not always a good business case although LEDs are more efficient in many cases?

The investment of an LED system is about 5-6 times more expensive than an HPS system. The lifetime of an HPS lamp is between 14,000 and 18,000 hours; the fixture itself much longer. The lifetime of many LED systems on the market is only 25,000 hours and this is for the whole fixture. The lifetime of LED fixtures can go up to 50,000, or even 100,000 burning hours. However, growers usually want return on their investment in 5-7 years. In most cases this cannot yet be reached.

LED's are more efficient than HPS or MH/CMH systems but they are also more expensive.

You can, however, bring LED's closer to the plants, which you see in interlighting solutions, where the light source brings the light in between the plants. In that way it also brings some warmth into the middle of the plant, instead of just on the top with discharge lamps and on the bottom with the heat pipes.

With LED's the spectrum can be fully controlled and we can create any light recipe we want. This means we can control photomorphogenesis and therefore what the plant looks like, influence taste or control the amount of certain ingredients used in a medicine or moisturizer.

The better control of the light spectrum provides huge advantages in respect to producing higher quality crops. The research into the effect of light spectra on varying crops and even varieties within the crops will bring more and more valuable business cases to the table.

LED is here to stay and as it evolves will slowly replace discharge lamps.

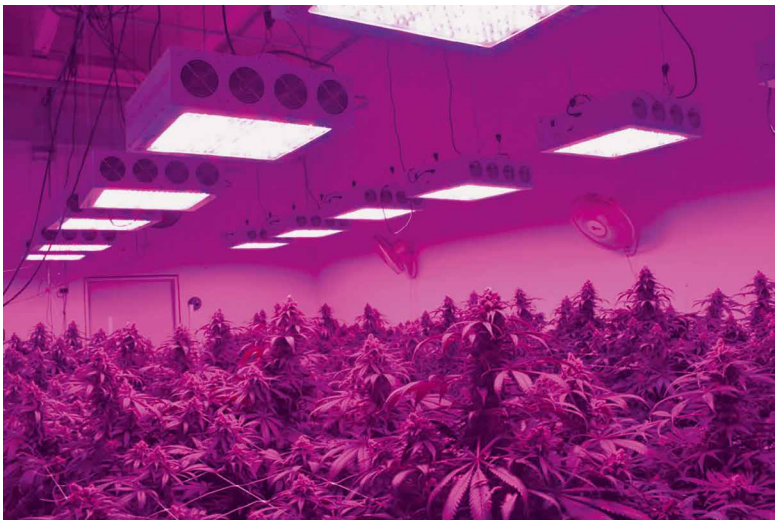


Figure 12:
Red and Blue LED spectrum in grow room for medicinal cannabis

Figure 13:
Interlighting in a greenhouse for cucumber

Figure 14:
Examples of vertical farms

LED in vertical farms

In vertical farms, LED is the light source of choice, only the older farms still use fluorescent tubes. The advantage of LED's is that they generate less heat and 70% of that heat is transferred to the back of the fixture and not towards the plants,

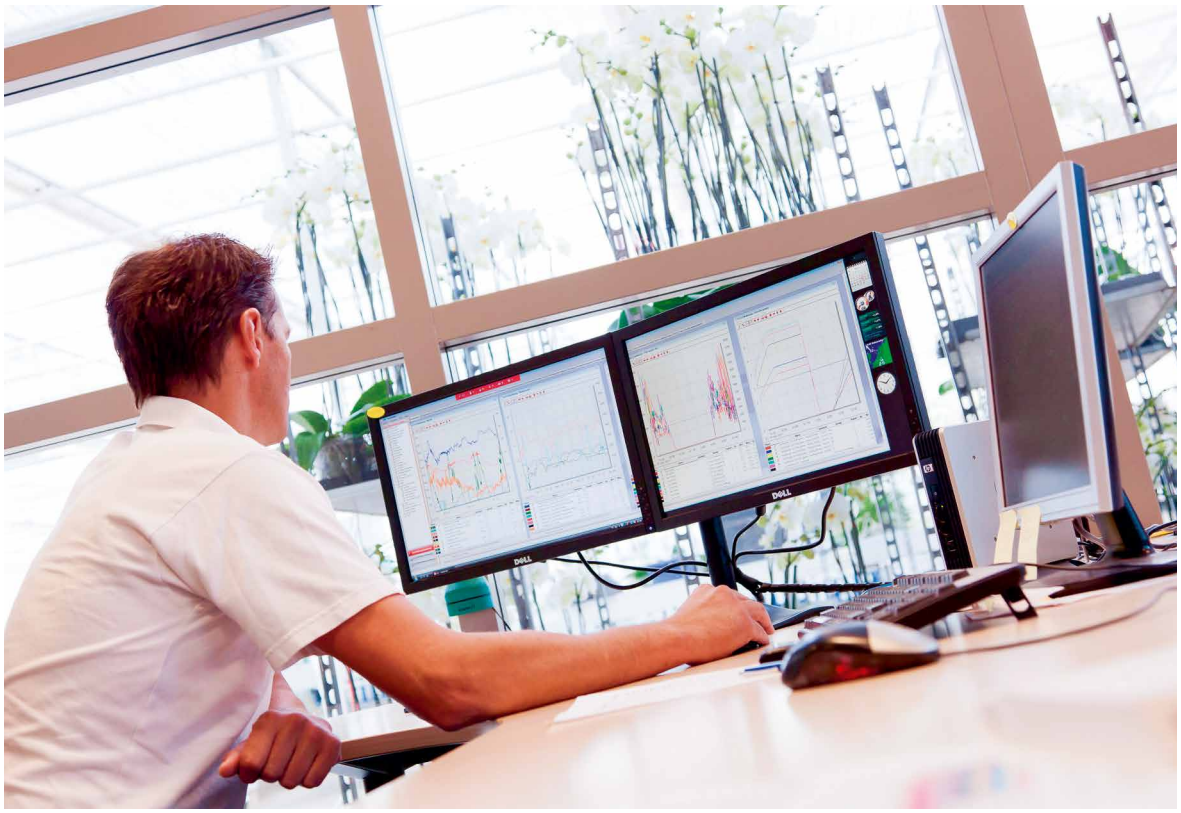


Figure 15:
Control systems & software

which means you can bring the light source very close to the plants, even up to 10 cm. This means you can have up to 4-5 layers per meter in height, with young/small plant material. Controlling the nutrient levels in the plants and fruits is also important in many of the crops grown in vertical farms. This is very important for companies in the pharmaceutical-, cosmetic industry and research centers.

There are many players entering the LED market. The worldwide market leader is Philips and in North America, Fluence (by Osram). Then there are many other players, like Hortilux, Heliospectre, Valoya and many others. LED's are relatively easy to produce and this market still needs to establish itself.

A Constant, Ideal Climate

The growing demand for food and crops is being met all year round. But not every environment and every climate allow this. That is why at Bosman Van Zaal have developed an efficient, modular climate system that makes this possible, irrespective of the production location. With the ClimaPora for greenhouses there is an innovative and sustainable climate technique, which is widely used for both vegetable and ornamental cultivation, all over the world.

Vertical farms

Vertical farming is one of the solutions to the problem of growing demand for nutrition. A multiple level growing system uses less surface area, energy and water. And production takes place all year round, resulting in a larger yield per m^2.

Vertical farms are used in areas that are limited in space (close to the world's largest cities) and where the environment is harsh (in space, on the poles, in deserts), but they are also used when the circumstances and the growth results need to be repeatable and the same over and over again, for example, in the pharmaceutical, or cosmetics industry.

Bosman Van Zaal creates vertical production systems, where durability, convenience and higher yield are paramount. Their Grow & Roll principle is an example of one of the components to their vertical horticultural systems.

In this concept all the expertise in the field of climate, cultivation systems, water, electricity and control systems is combined in a small volume of a few m^3. The mobile container with multiple layer carts (Danish Trolley) acts as a closed laboratory for the efficient cultivation of seeds, cuttings and crops. In the container, every desired climate is simulated by the setting of temperature, humidity, light, CO_2 and irrigation. Each module has its own docking station that includes a water connection and electrical connection for all different types of LED lamps. Air circulation can be fine-tuned so that temperature problems (and therefore plant diseases) are minimized.

The climate is controlled by a climate computer that not only controls the growing conditions, but also collects data for analyzing and AI.

With indoor grow facilities or vertical farms, it is all about control. Control of the air coming in,

control of the water and nutrients coming in, control of temperature, humidity, light level, light spectrum, air speed, CO_2 levels etc. Everything can be controlled into the smallest detail.

Conclusions and Future Prospects

It is expected that more and more cultivation will take place in a controlled environment and location, crop, budget and outside conditions will determine what kind of grow facility is built. We see an increase in mid tech greenhouses in Asia, where now a lot of simple foil "tent"-constructions are used. In Europe and North America there is an increase in semi-closed and fully closed greenhouses and grow chambers. Especially in Cannabis cultivation there are a lot of fully closed greenhouses, or grow rooms because these growers do not want the scent to spread to the surrounding area, as this is often a requirement from the local government when given permits.

In Asia it is expected that fully closed environments will also increase over time as they catch up to the state of technology in Europe and North America. Environmental circumstances like air pollution around the major conglomerates will play its role, because consumers who have more money to spend will ask for safer products, with less pollution.

Sensors and fully computer steered growth will also continue to increase. In research facilities researchers already use sensors to measure temperature, humidity, airspeed, water level in the soil, nutrition levels in the water delivery and water leaving the gutters, CO_2 levels in the air, CO_2 capturing in the leaves, drones flying over the crops detecting spots on the leaves, or other symptoms of disease, light sensors, measure Brix numbers (sum of the pounds of sucrose, fructose, vitamins, minerals, amino acids, proteins, hormones, and other solids in one hundred pounds of plant juice) to determine content/flavor in fruits and many other things that can be thought of to measure in the future.

One of the main things in the photosynthesis process that can be measured and controlled is the light in wavelength where LED can compensate sunlight to specific ratios, which are ideal for the plants in various stages of the growth. For example, for many plants adding blue light is favorable for the development of roots, but it also stimulates the opening of the stomata (for CO_2 capture). In the morning this helps to keep plants more compact, suppress flower development and so on. The ratio between red and far-red light determines the stretching of the plants, flower and fruit development, leaf spreading, leaf size etc. UV light is said to stress plants. In the right amounts this can make the plants stronger, increase lycopene content, or specific ingredients and also fight fungi.

Currently, artificial light is delivered in a specific set of wavelength combinations and in discharge lamps this cannot be altered. LED's could be completely sensor operated, compensating for missing wavelength in the sunlight or adding specific wavelengths in the morning or the evening, etc. The loss of light when a cloud passes by can also be compensated.

Another important thing in our changing world is limiting run off (fertilizers, growth hormones/-inhibitors, pesticides etc.) and minimizing the loss of resources (water, nutrients, heat, light, CO_2) has already taken a huge step forward. The same is true for biological pest control, which is used a lot in, for example, The Netherlands, but not so much in the more southern countries in Europe, or the rest of the world. Biological pest control uses natural predators of the infestation, with Aphidalia (ladybugs) against lice as the most well known. This natural way of controlling problems or pests in crops limits the need for pesticides and therefore minimizes the amount of chemicals in our food. In both cases the rest of the world needs to follow if we want to lower our CO_2 levels, preserve our natural resources and not pollute this beautiful planet. ■

Combining Sunlight and LED Grow Lights for Ultimate Plant Growth

Modern day greenhouses combine the usage of natural and artificial light to improve both the quality and quantity of their produce. Luis Rivera, enthusiastic spectral science, indoor farming and food production specialist at Advanced LED Lights, explains how relying on both natural and supplemental LED grow lighting improves growth rate and increases profit.

It's a well-known fact that plants need proper lighting in order to grow healthy. The Sun has been providing that vital source for the greenery way before humans walked the Earth. Is it sufficient? Yes, obviously it works out great for the wild plantations. But can we do even better when it comes to cultivating the perfect crop? Yes, by using supplemental grow lights.

In modern days we have access to so much innovative practices for growth moderation, that it would be a shame not to take advantage of them. With LED grow technology, the light could be adjusted according to the specific needs of each plant and its current growth phase.

The Light Requirements for Growing Plants

When it comes to cultivation, the light requirements of any type of crop may vary. While some plants require strong sunlight (eg. vegetables), others would prefer more shady or low light environment (eg. foliage plants).

Especially when it comes to greenhouse or indoor farming, where the natural light is insufficient, growers need to make sure their plants would thrive under the correct light, temperature and color spectrum. That is when artificial lighting saves the day.

Some plants require photoperiodism

Photoperiodism is a process that explains the reaction of the plants to the length of dark and light periods. In nature, wild plants respond to the day-night and seasonal cycles. When it comes to domesticated gardening, some plants require both dark and light hours, in order to flower.

There are two types of organic reactions to the photoperiodism - obligate and facultative response. An obligate response stands for the statement that the plant would only flower if it grows under a particular photoperiod. On the other hand, facultative response would mean that the plant would be able to flower regardless of the photoperiod, however it could flower much faster under a certain photoperiod.

Different greens, different needs. While some plants prefer longer days, others prefer longer nights, and some would grow best regardless or on balanced light/dark periods. Those preferences can separate them on types of "long-day," "short-day" and "day-neutral" plants.

"Short-day" means the light phase of a plant is no more than 12 hours and it flowers when the day length is shorter than usual. A "long-day" plant is one growing with a light phase longer than 14 hours. Such crop would only flower when the photoperiod is longer. "Day-neutral" plants are those whose flowering is not affected by the photoperiod at all [1].

Photosynthetically Active Radiation

Photosynthetically Active Radiation (PAR) is a scientific term used by biologists when measuring the amount of light available for photosynthesis. It defines the spectral range of solar radiation from 400 to 700 nm in wavelength.

PAR is often measured in Photosynthetic Photon Flux Density (PPFD), with unit of mol/m²·s. In general, it is calculated as follows: the amount of 400-700 nm range light protons received on a specific surface for a certain period of time. It can be easily formulated as micromoles per square foot per second (µmol/m²/s). This measurement type is extremely valuable for the growers, since it takes into consideration both the amount of light that reaches the plant and its intensity.

During the various growth stages, the grow light PAR output has to be adjusted accordingly. For seedlings, it needs to be set low (200-400 PPFD). Plants in a vegetative state would usually require a middle range output (400-600 PPFD). Flowering stage plants have higher PAR requirements (600-900 PPFD). Note that you would need a PAR meter to measure the output of your grow light [2].

Light Quality Assessment

Plants have various receptors for perceiving light quality and colors. Phytochrome is a main receptor which is highly responsive to the amount of red light and far-red light (R:FR). Throughout various researches and experiments, it was determined that the Red:Far-red ratio (R:FR) is highly relevant when measuring light quality.

Through the years, the calculation of the red:far-red ratio have changed. In 1982, Smith has defined R=655-665 nm & FR=725-735 nm; in 1963 Kasperbauer counted R=640-650 nm & FR+725-735; and in 1987 Mortensen and Stromme used the R=600-700nm & FR=700-800nm. Natural sunlight spectrum provides similar estimates of the R:FR ratio.

LED lights' manufacturing specifications vary for each model. However, studies have shown that the Mortensen and Stromme method of calculation with the PPFD (mol/m²·s) unit would lead to the most stable light quality measurement [3].

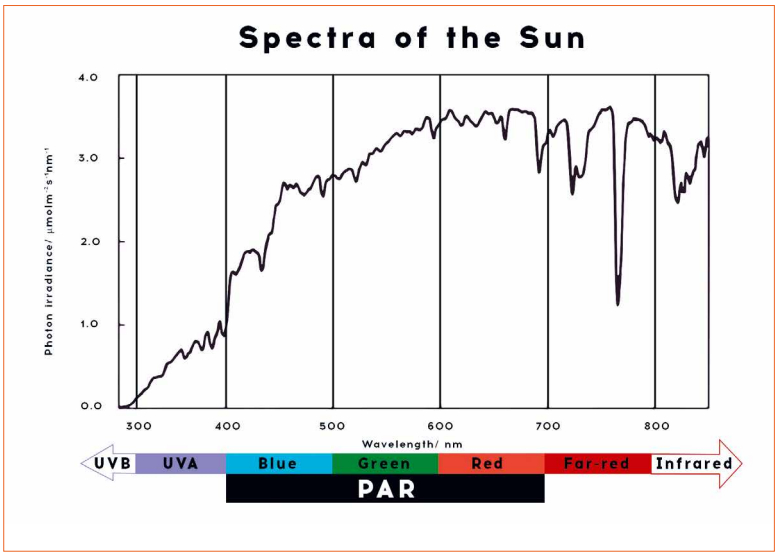


Figure 1: Position of PAR in the spectra of the sun measured in 2014 at the Stockbridge Technology Centre, Cawood, North Yorkshire

How Plants React to Different Types of Light

UVB light response

UVB is an ultraviolet light that is out of the visible color spectrum. A plant's photoreceptors for UVB are sensitive to light with wavelength of 280-330 nm. Most of the short-wavelength sun radiation like UVB does not reach the Earth at all, due to the protective layer of atmosphere. This is good news since high levels of this kind of ultraviolet exposure would potentially harm all living organisms.

No doubt why UVB LED grow lights are particularly expensive. They are mostly being installed to stimulate the growth of herbs and weed, since they increase the quantity of essential oils in the greenery.

UVB LEDs are a promising solution that could be hazardous if misused. Plants exposed to UVB radiation have a drastic change of pigmentation, strong, tough and robust leaves [3].

Blue and UVA light response

Each blue light photoreceptor of a plant utilizes certain functions and techniques in order to deliver quality produce and influence the growth process. The most valuable blue light photoreceptors are phototropins and cryptochromes.

Main function of phototropin includes modifying cellular processes without affecting the genes. The range of plant responses to blue & UVA lights includes leaf flattening, chloroplast movement, production of anthocyanin [3].

On the other side, cryptochromes work by altering a plant's gene expression. The response of this photoreceptor to blue light consists of commencing the circadian rhythm, pigment regulation, flowering inhibition of hypocotyl elongation [3].

Green light response

Currently there is no evidence of existing green photoreceptor in plants. But this does not mean that the green light is unreliable whatsoever. Some receptors like phytochromes react to the green spectra. And cryptochromes, for example, can be neutralized by it.

With its 500-600 nm in wavelength, the green light plays a supportive role to plant's growing. The major effect that green light range has on plants is the increase growth rates due to the direct impact on vegetation and photosynthesis processes [3].

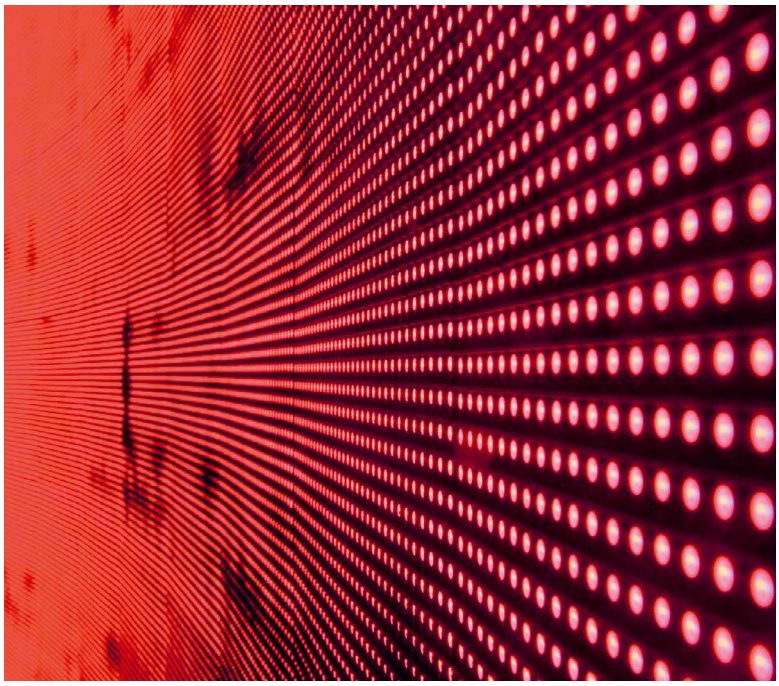


Figure 2:
LED Grow Lights omitting red light

Red and far-red light response

Of all plant receptors, phytochromes are the most responsive to the Red and Far-Red lights. Phytochromes are stimulating many biological processes like flowering, germination, leaf expansion, circadian rhythm entrainment and chlorophyll biosynthesis.

There are two widely familiar types - phytochrome A (phyA) & phytochrome B (phyB). PhyA is easily activated by both far-red and red lights, while the active state of accumulation happens primarily during the dark hours. On the contrary, phyB is absorbing mostly red light and unlike phyA, it goes into inactive state at night [3].

Supplemental Lighting vs. Natural Lighting for Growing Plants

Do plants grow better in sunlight or artificial light? What are the advantages and disadvantages of both growing methods? How does sunlight help plants grow? How can we successfully combine them? How can we reach the full potential of the crops?

Join us on a quest of finding the answers of the most common curiosities of farming.

Natural lighting

The benefits of a plant grown with natural light cannot be denied. After all, traditional farmers had no access to modern technology that allows supplemental installations. And yet they managed to keep their crops healthy, unless bad weather or a natural disaster got in the way. The unpredictability of such unfortunate events is one of the reasons many modern-day farmers rely on greenhouse sustainability.

But is it enough to protect plants from external impact?

Sunlight is a source of energy, essential for the photosynthesis process. The sun provides a sufficient supply of blue and red light, which plants require in order to grow healthy. On the contrary, not all domesticated greens can fully rely on it to deliver the best quality produce.

The biggest disadvantage of natural light is its inconsistency. Without the adequate food source provided, the plants would not be able to reach their full potential. The lack of proper lighting interferes with the photosynthesis cycle, resulting in crop's growth being stalled on a dark night and a cloudy day.

Sunlight might be a must for outdoor farming but it is not the ultimate solution for the greenhouse greenery. This is where LED grow lights change the game [4].

Supplemental lighting

Supplemental lighting allows us to sustain a plant's growth without any sunlight. What makes it more efficient than the sun, is the possibility of the individual approach to the greenery. Many kinds of grow light sources are available on the market. Some famous examples include plasma and sulphur lamps.

Plasma lamps contain a gas that emits light when heated by high frequency radio waves. They do not have an electrode and once lighten up, plasma installations mimic the spectrum of the sun. Sulphur lamps work in a similar way. The difference is that the glass vessel of the bulb contains sulphur and once heated, it forms the plasma. The gas mixture in the lamps could be modified to fit the right spectrum, however the spectrum remains fixed once it is constructed.

LED lights, on the other hand, are technologically improved. They are more environmentally friendly, cost effective and totally innovative with the solutions they provide for indoor and greenhouse farming. The most important advantage of LED grow lights is that their intensity, spectrum and can be adjusted according to specific needs of a certain plant. Additional moderation is available at all times.

Such installations boost a greenery's growth as well as its flowering and fruiting states. It also quickens the transition from a seedling to a fully-developed plant. By being able to control the intensity, exposure, spectrum and temperature, the farmers can aim for optimal results. Of course, optimal results lead to regular harvesting and financial gains.

When it comes to artificial lighting growers should consider operational and maintenance costs.
While indeed the sunlight is free, a LED system installation is a financial investment that comes with long term profits.

Requirements on High Quality LED Grow Lights and Their Key Features

In many respects, the basic requirements for horticulture luminary design are quite similar to the requirements in general lighting applications, recognizing thermal requirements, droop, and optical parameters are equally crucial.
But there are also some differences and additional features to consider.

The wavelengths emitted by an LED grow light are one of the most essential features when choosing the best installation. In simple words, the wavelength output feature of LEDs would refer to the relevant PAR adjustment of the color spectrum visible to the human eye.

It's a well-known fact that plants absorb only some wavelengths, while others are mainly reflected. Scientific tests have exhibited that red and blue light wavelengths are particularly vital for the well-being of a plant. That being said, PAR is important because by using the proper grow lights with high wavelength output, the crops would be able to develop faster and healthier by depending on way more usable light than usual.

Horticulture growers are used to various measurement terms when it comes to LED specification, with Lumens, PAR and Lux being the most commonly used.
While Lumens and Lux are related to the human eye responsibility curve, PAR is the preferred measure for plants as it is vital to know the actual amount of light that the plants absorb.

Using Lux and Lumens is not recommended in plant applications, unless a conversion to micromoles

Figure 3:
LED Grow Lights are one of the most popular supplemental lightings.

or another useful light unit is available. That is the reason why PAR photon radiance is the ultimate measurement that provides the most authentic information for grow light comparison.

Light intensity is a valuable feature in any LED grow light, especially when it comes to comparing different types of LED systems. The proper levels of intensity would assure healthier growing plants, however higher levels can burn a plant's tissue and irreparably harm the crop.

It needs to be mentioned that high quality LED might be more expensive than regular ones, but the price to pay is definitely worth it. Such diodes are being manufactured to meet certain specifications like emitting proper wavelength light as well as sustain their integrity in a long period of time.

Due to their high efficacy, compared to other supplemental light sources, LEDs just generate some low levels of heat.
Therefore, unlike other grow lights on the market, high quality LED lights are not harming the plant tissue when put extremely close to the greenery. With LED grow lighting, heat regulation is most surely on point.

Benefits of Supplemental Lighting

Installing supplemental lighting systems comes with irrefutable benefits, as described below.

Availability

While the availability of sunlight depends strictly on weather conditions, the LED greenhouse lights are always available- all you need to do is plug them in.
With supplemental solutions you can grow all year round, no matter the season.

Spectrum, exposure and intensity control

LED grow lights provide the ultimate control over the vegetation of your crops. By using artificial lighting, the temperature produced and the light spectrum can be adjusted in a way that would fit the needs and requirements of every plant.

Faster growth

Greenhouse LED grow lights can supply the light required individually for each plant, while also stimulating the photosynthesis process.
You should just make sure to do the proper calculations beforehand and adjust them accordingly for ultimate results. The plants mature way faster than the ones depending strictly on the power of the sun.

More harvest, more profit

Ultimately, faster growth leads to fully developed plantations in a shorter time period, which extends the growing season. The benefit that comes along is the opportunity to optimize the harvesting process and therefore, increase your profit.

Benefits of Adding LED Grow Lights in Greenhouses

Greenhouse LED lights are a suitable solution for meeting the demands of both hobbyists and commercial growers. The ability to grow plants without sunlight actually improves the quality and quantity of the crops.

Useful during winter and bad weather

Sometimes nature has a mind of its own and it is hard to predict unpleasant weather conditions. When cloudy or rainy days strike unexpectedly, farmers need to act in order to protect their greenery.

An appropriate step would be to set up an artificial environment by utilizing supplemental lighting in the greenhouse. The LED grow light technology provides extra light for the plants, stimulating their growth whenever sunlight is not available.

Taking this into consideration, greenhouse LED lights are a must for the winter season, especially in places with a northern climate, where temperatures tend to be lower. By protecting the crops from the cold, artificial lightings actually extend the growing season.

It is cost effective

The merge of indoor environmental controls with sunlight in a regular outdoor setting is the most efficient solution for greenhouse farming, particularly when it comes to bills and reducing costs.

Providing less energy consumption and heat emission, greenhouse LEDs would be your wallet's best friend.

Greenhouse LED lights can also lead to major yield increase because of their supplemental qualities of improving the production volume.

Environmental benefits

Outdoor farming relies on sunlight to help plants vegetate. The artificial light technology, on the other hand, is only supplemental to the whole process.

Thus, due to the limited usage of the LEDs (only when the natural light intensity is low), in a well-designed concept, it is safe to say that adding grow lights in greenhouses is an environmentally friendly decision when compared to long transportation distances and vertical farming without the use of natural sunlight. - The carbon footprint and energy consumption may be vastly reduced.

More Plant Lighting Strategies

One of the best strategies is usage of dynamic lighting. Whenever solar intensity is above a certain level or the daily light requirement level has exceeded, the dynamic system turns the lights off. Moreover, those installations can adjust the on-off time of artificial lighting and its spectrum automatically, according to the day-night cycle and weather changes.

Another popular strategy consists of the need to achieve balance between several desirable qualities. Sometimes, growers compromise on one plant quality, in order to boost another. For example, enhancing a fruit's pigmentation right before harvesting period might lead to a reduced yield, but it grants a better production appearance which can be good for sales.

Every cultivator needs to consider the best light treatment for their crops. With LED technology, choosing the correct lighting strategy and applying it is easier than ever. The flexibility of the installation allows customization of lighting programs and adjustment of the various settings throughout the whole growing process and development stages.

Correct implementation of those strategies would most surely lead to reduce of energy and improvement of produce quality [3].

The proper combination of sunlight and LED grow lights is revolutionary for greenhouse farming [4].
In a progressive world where one can take full advantage of both the artificial and natural light benefits, plant cultivation will never be the same. ■

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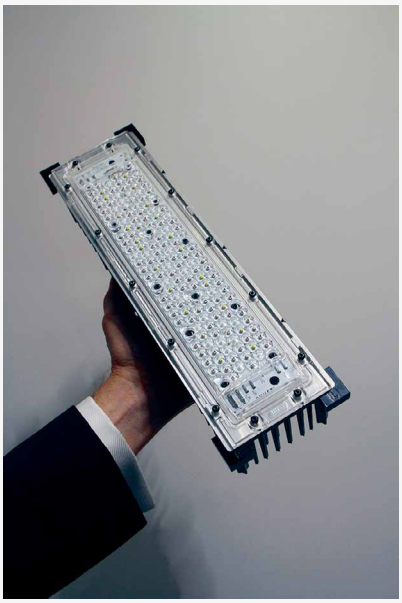

Horticulture lighting is one of the bearers of hope for future business of the lighting industry. Distributors like AVNET are well prepared (@LFi 2019)

Next LpR

ENVIRONMENTAL FRIENDLY DESIGN
Issue 75 - Sept/Oct 2019

TECH-TALKS BREGENZ

Wilfried Kramb - Founder and CEO of a·g Licht

When Zumtobel announced that Mr. Kramb would be attending their Light Forum, LED professional jumped at the opportunity to invite him to give an interview for the TTB. We talked about his philosophy behind lighting design, his opinion of the new LED opportunities, and connected lighting. But the main theme was the "human factor" and environmental aspects.

RESEARCH

"Best Papers" at LpS 2018: Temperature Profiling of Secondary LED Optics by Infrared Thermography

Over the last few years, the power density of white LEDs has increased dramatically. This may also affect secondary optics, especially if the secondary optic is made out of a polymer, as the heat distortion temperature (HDT) is at 95°C and 122°C. The research describes an analyses method using infrared thermography on PMMA and PC.

An Overview of Environmental Assessment Methods for the Circularity in the Lighting Industry

The introduction of LEDs has contributed to saving 200 million tons of CO_2 per year in the EU. Besides energy consumption in the use of those products, aspects, such as the collection and recycling at the end of the life cycle are important in order to convert the lighting industry to a circular economy. Relevant environmental metrics will be explored to help inform the reader about circular economy and Industry 4.0 strategies to achieve a sustainable lighting product.

TECHNOLOGIES

Inspiration from a Parallel Universe: Reviving the Vision of OLED

Once considered the rising star of the lighting world, OLED has arguably contributed more to elevating lighting design to an art form than any other single component. However, the technology has still its drawbacks and a new concept using LEDs is challenging the unique selling point. The authors explain and compare both technologies.

12 Years of Progress in White HP LEDs

In 2007 LED professional analyzed the real practical performance of white HP LEDs, a difficult and complicated task as data sheet information from the different brands was not consistent. A newly published analysis of the recent HP LED generation motivated the authors to combine both findings to show the progress of the last 12 years.

SPECIAL TOPIC

The Adverse Ecological Impacts of Light Pollution: The Role LEDs Play in Mitigation

With the negative effects of artificial light at night on ecosystems increasingly understood, attention is now turning to the ways in which these impacts can be mitigated through uptake of novel technology and lighting strategies. The current evidence for costs and opportunities associated with uptake of LED lighting is discussed, with important directions for future investigation highlighted.

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EDITORIAL CALENDAR 2019

ISSUE N°	IN THE SPOTLIGHT*/**	DUE	ARTICLE DUE	ONLINE PUB.	PRINT PUB.
71 Jan./ Feb.	**TECHNOLOGIES FOR HEALTH & WELL-BEING** Efficient lighting has become a prerequisite. Ongoing discussions question whether efficient lighting is also healthy lighting and if it supports well-being. Findings, technologies, designs and applications supporting health and well-being are the focus of this issue.	Oct. 15, 2018	**Oct. 22, 2018**	Jan. 15, 2019	Feb. 01, 2019
72 Mar./ Apr.	**FUTURE PROOF SYSTEMS & SOLUTIONS** Most buildings are constructed to last at least four decades. Owners and operators are only willing to invest in long lasting future proof solutions for the infrastructure. The topic of this issue is the question of if and what future-proof solutions and technologies are available.	Dec. 17, 2018	**Jan. 04, 2019**	Mar. 15, 2019	April 01, 2019
73 May./ June	**DISRUPTIVE TECHNOLOGIES & APPROACHES** A good part of the lighting industry suffers from high production costs – especially in Europe and the US. New concepts, designs, materials and manufacturing methods may be advantageous. This issue reveals the most ingenious approaches.	Feb. 25, 2019	**Mar. 04, 2019**	May 15, 2019	June 03, 2019
74 July/ Aug.	**TECHNOLOGIES FOR SPECIFIC TASKS & APPLICATIONS** Light is not only used for illuminating rooms and open spaces. The applications of LEDs are manifold. This issue acknowledges the importance of LED light sources in automotive, horticultural, medicinal, cosmetic, and environmental applications, to name just a few.	April 24, 2019	**May 06, 2019**	July 16, 2019	Aug. 01, 2019
75 Sept./ Oct.	**ENVIRONMENTAL FRIENDLY DESIGN & ENGINEERING** The EU Commission supports the move towards a more circular economy. Additionally, research demonstrates that artificial light may negatively affect the environment. Technologies, designs and solutions that recognize these two aspects are addressed in this issue.	June 26, 2019	**July 05, 2019**	Sept. 02, 2019	Sept. 24, 2019
76 Nov./ Dec.	**TECHNOLOGIES FOR VISUAL PERFORMANCE & COGNITION** Some research results suggest that the spectral properties of a light source have great influence on visual performance, cognition and arousal. But it is more than just the spectrum that counts. This issue presents supporting concepts, technologies and solutions.	Aug 06, 2019	**Aug 26, 2019**	Nov. 15, 2019	Dec. 02, 2019

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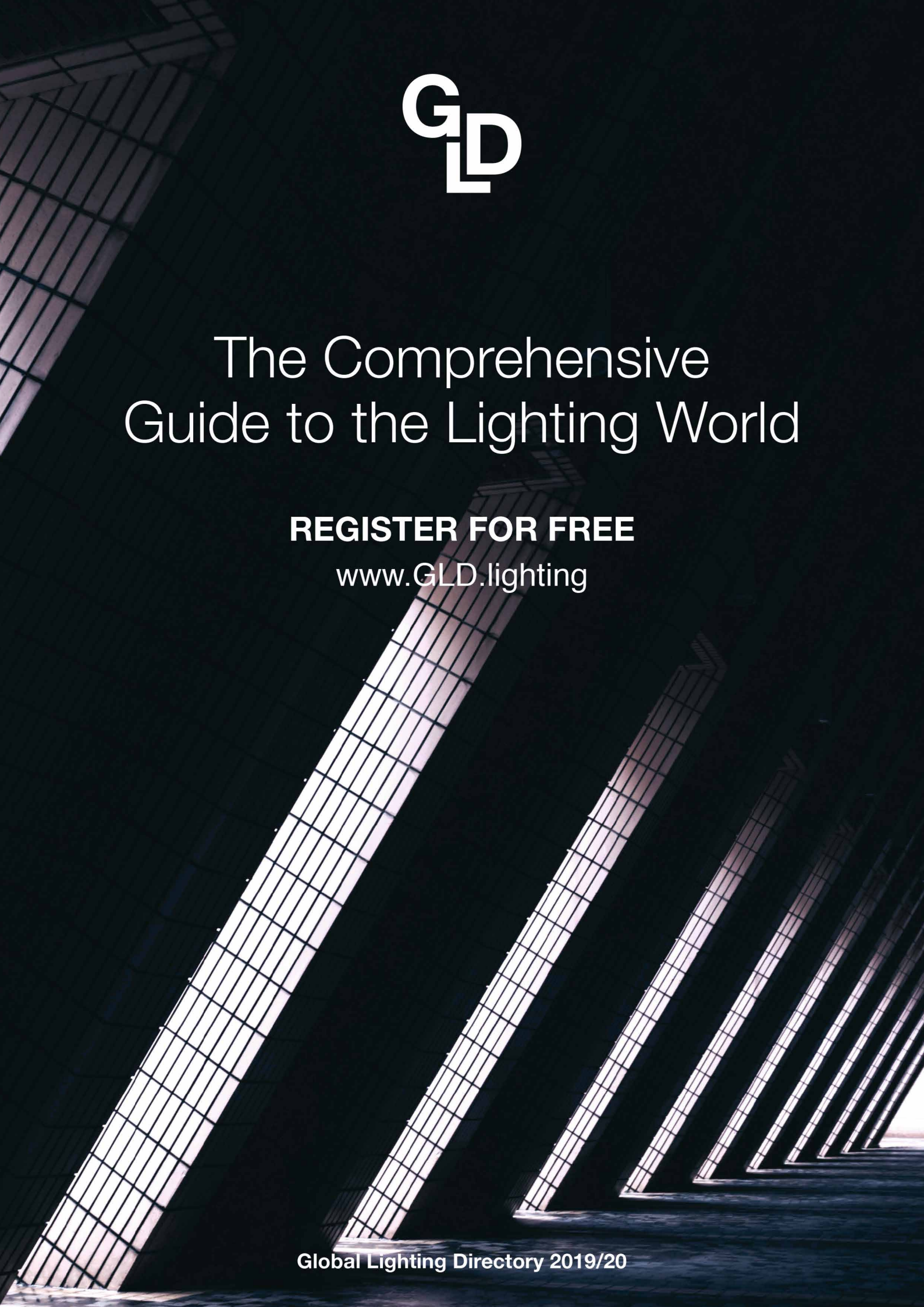
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