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LED professional Review

LpR

The Global Information Hub for Lighting Technologies

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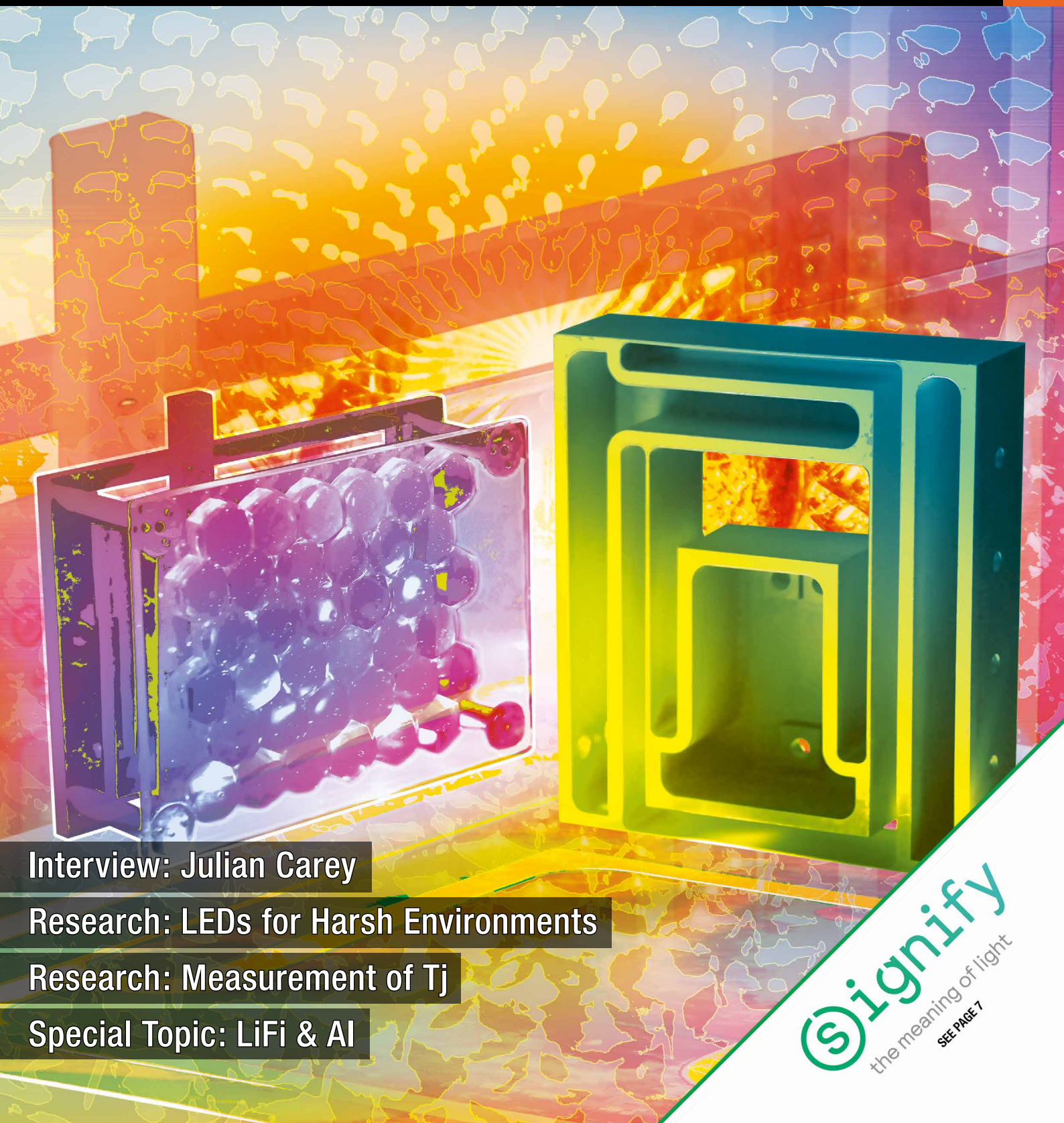

Interview: Julian Carey

Research: LEDs for Harsh Environments

Research: Measurement of Tj

Special Topic: LiFi & AI

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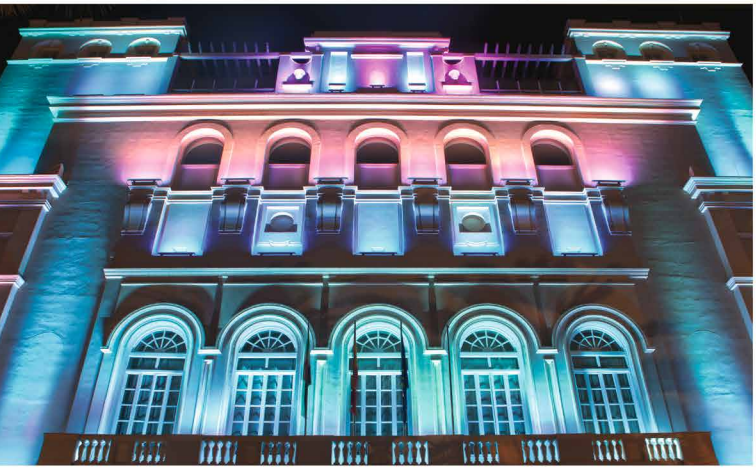
Pushing the boundaries of light.



Leaps forward in LED technology have opened up a wide range of new and previously underserved markets that demand innovative applications. Seizing these lucrative opportunities in Horticulture, Architecture, Entertainment, Sports Lighting and Retail is easier with Lumileds on your side.

Our relentless pursuit of superior performance and quality of light ensures that when you integrate Lumileds LEDs into your application-specific designs, they will stand up to the most demanding requirements. And because being first to market with differentiated solutions is essential to outpacing the competition, Lumileds stands ready to help you streamline manufacturing processes and optimize supply chain management at every turn.

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Future Lighting

This issue of the LED professional Review (LpR) covers some interesting approaches and innovations in the lighting sector.

Kyra Xavia gives us food for thought in her commentary on the careful handling and use of light. The two articles by CIE and Zhaga/DiiA show the importance of standardization from the technological module standards to the new standards for Horticulture Lighting.

What can we expect from laser light? This was the question we asked the manager of SLD Laser, Julian Carey, in our Tech-Talk BREGENZ. Although laser light is used today in special applications, there are still some hurdles for use in general lighting.

Our research topics deal with LED applications in harsh environments and we investigate how junction temperature can be measured accurately and quickly. Quality engineering in the LED area especially focuses on the lifetime determining parameters of the chip temperature of LEDs.

We also deal with the topic of LiFi and 5G and talked to the leading head of the division, Professor Haas. In his article he describes the future of these technologies. And of course, the topic of Artificial Intelligence also has to be included in an edition about the future. Where and how are the points of contact between AI and lighting?

With this in mind, I hope you enjoy reading this issue. We always look forward to your feedback and suggestions for further topics!

Yours Sincerely,

Siegfried Luger
Publisher, LED professional

PS: A note about LpS 2019
The LpS 2019 program booklet is available now. You can download the program brochure at www.LpS2019.com for information about all the lectures. Buy your ticket by July 2nd and receive a 20% Early Bird discount.

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SPECIAL TOPICS

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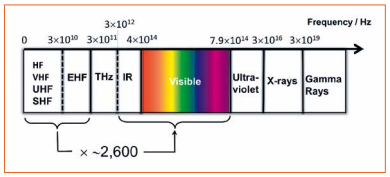

ADVERTISING INDEX

CERTAMATCH SOLUTIONS

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The Market Trend

Average unit prices of high-running indoor LED fixtures are plummeting.

OEMs are resorting to importing and reselling finished fixtures or using lower cost components with minimal warranty or technical support in order to remain competitive.

There is Another Way...

What if you could have **high quality** components at a **competitive price**?

What if you could have onshore sourcing for **shorter lead times**?

What if your components had a **5 year limited warranty** that is serviced by your components supplier?

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- DLC Premium or Standard combinations
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Kyra Xavia

Kyra Xavia is a researcher, educator and investigative journalist based in New Zealand. Her roles as general secretary of the Light and Lighting Research Consortium (LLRC), delegate for the International Dark Sky Association (IDA), New Zealand Ambassador for Women in Lighting 2019, and co-leader of the Dunedin Dark Skies Group, involve educating decision-makers and the public about the importance of responsible lighting, nocturnal placemaking and the value of darkness. Recognised in New Zealand and abroad for her advocacy in these matters, Kyra has co-authored research papers and published articles specific to this subject.

CARE, CAUTION & AWARENESS ARE NEEDED WHEN USING LED LIGHTS

Lighting is a vast and complex topic, yet despite the confusion that surrounds LED technology, it's clear we're failing in a big way in its safe application and deployment. Nowhere is this more evident than with street lighting.

Although LED technology has enabled the profuse use of cheap light with energy, operational and maintenance savings appealing to municipalities around the world, such light happens to be brighter, more light-polluting and disruptive than the light it commonly replaces, causing many issues.

How can LED lighting, as applied today, be considered an improvement if it injures eye tissue, prevents quality sleep, causes pain and discomfort, harms health, impairs vision, hinders wayfinding, jeopardizes driving, compromises safety and security, degrades the ambience and atmosphere of neighborhoods, historic sites and architecture, puts flora and fauna at risk, threatens eco/astro tourism, worsens light pollution and steals away the stars in the sky?

Quite simply, it doesn't matter how energy efficient a light source is, how long it's lifespan, or how economic it is to operate and maintain - if it causes degradation and harm it's a false economy.

While the adverse effects of blue wavelengths of light at night can no longer be dismissed, cool white LEDs are also infamous for their harsh, clinical, phototoxic light, strong contrast, blinding brightness and dangerous disability glare. Cheap and poorly designed LED luminaires can produce non-uniform light distribution, unwanted light trespass, flicker, and electromagnetic interference. Also, due to the intensity of light emitted, the chips in an LED array need to be hidden from the naked eye. Furthermore, although there's less upwards light spill, shorter blue wavelengths of light directed at the ground readily bounce back into the atmosphere increasing light pollution.

It's specious to claim bright white lighting improves safety and security, and we need to be careful about declaring "improved" light quality too. Such statements need to be questioned and the full equation understood. Education and transparency are key so people understand what this involves. Emerging evidence and millions of years of evolution counter these assertions. Indeed, the more we discover about photobiology, chronobiology, and human vision, the more obvious it is that lighting our streets brightly at night to look like day is misguided.

Biology on Earth developed with light/dark cycles, and like many other organisms, humans are exquisitely sensitive to light. Our health hinges on using the least disruptive light at the night, and restorative rest depends on complete darkness. This means artificial light needs to be as biologically responsible as possible.

Complicating matters further, there's still much we need to learn about light in general and how the body responds to it. A paradigm shift in our use of light is necessary because light has the same powerful impact on the human body as pharmaceuticals. By default, the lighting industry has a responsibility to robustly test LED products to prove their safety and suitability before they enter the market.

So, what does responsible street lighting look like? Ideally, it's shielded, indirect, soft on the eyes, evenly distributed, and as dim as practical - just the right amount of light where and when needed. LED lights should be no brighter than the light it replaces, with a similar or improved scotopic/phototopic (S/P) ratio of 0.4 to 0.6 (S/P ratio characterizes how much light emitted from a light source is useful to the human eye under scotopic vision and how much light pollution can be expected). The light is warm (2200 K or lower) with an appropriate spectral power distribution (minimal blue and green wavelengths) and it provides adequate color rendering. Thankfully, there are innovative and visionary companies leading the way. ■

K.X.

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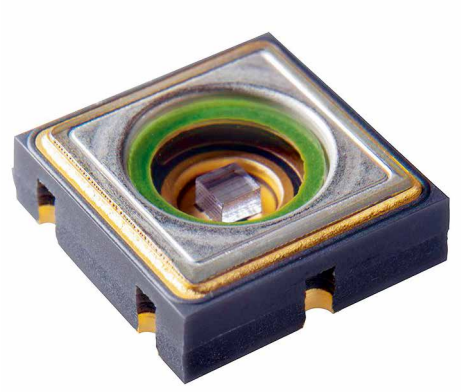
Nichia Launches a 280nm Deep UV LED

Nichia Corporation is proud to introduce a new Deep UV LED, Part Number NCSU334A. Nichia has already had significant success over the years with UVA LEDs, specifically in convention resin curing applications. Nichia's new 280 nm UVC NCSU334A will be able to address mass market goals for water purification and air sterilization using Solid-State Lighting.
With its small size (6.8x6.8 mm) and strong performance (55 mW typical optical power at 350 mA), the NCSU334A allows for system miniaturization and long-life solutions where previous technologies could not.



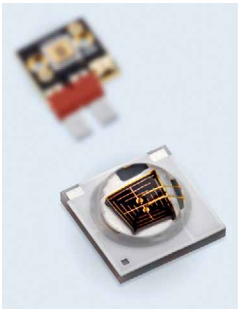
Nichia's new Deep UV, 280 nm LED, Part Number NCSU334A addresses mass-market goals for water purification and air sterilization

Conventional UVC LEDs (200-280 nm) have problems with a more complex crystal growth and a shorter life than UVA LEDs (365-405 nm). Through Nichia's unique crystal growth technology that has been cultivated for many years in UVA LEDs, Nichia takes great pride in successfully developing the world's highest quality, high radiant flux, long life UVC LED.
The NCSU334A achieves a significant lifetime improvement versus conventional UV lamps. Additionally, this LED uses a newly developed hermetically-sealed package, making it a highly reliable product that is not as susceptible to external environmental conditions and can therefore be used in various harsh environments.

Nichia expects this LED to contribute to the complete replacement of mercury lamps, which create environmental issues for the world's future. Nichia will continue to improve the characteristics of its UVC LED portfolio and aim to create a new Deep UV market leveraging the characteristics of Solid-State Lighting. ■

Luminus Adds Eleven High-Intensity IR LEDs

Luminus Devices has significantly expanded its portfolio of high-power infrared (IR) LEDs with eleven emitters designed to address the rapid expansion of automotive, consumer, machine vision, medical, and security applications. The Luminus IR SST LEDs are now offered in three wavelengths - 810 nm, 850 nm, and 940 nm - and six beam angle options ranging from 40° to 130°. The high radiometric power output and low thermal resistance allow system designers to reduce the number of emitters and overall footprint for a broad range of infrared applications.



Typical Radiometric Power @1A by wavelength and beam size.

	810nm	850nm	940nm
40°		800mw*	
50°		1500mw	1470mw
70°		800mw*	
80°	1300mw		
90°	1470mw	1500mw	1470mw
130°	1470mw	1600mw	1470mw

*denotes single-junction LED

IR LEDs are essential for many applications and with the expansion of the high-power infrared (IR) LED portfolio, Luminus offers a solution to any requirement

Nine of the newly-introduced IR products are based on dual-junction technology which nearly doubles the power density and keeps efficiency virtually unchanged. This makes it easier to develop solutions with much higher radiant intensity and more compact designs. The IR SST product line delivers very high radiometric power, up to 1600 mW typical at 850 nm and 1 A drive current, and radiant intensity in excess of 1300 mW/sr.

"Our dual-junction technology allows us to double the power density in the same footprint," said Yves Bertic, Senior Director of Global Product Marketing. "Now product designers can address applications that need longer reach and more intense and focused beams."

Optical options have also been expanded to support the increasing variety of infrared applications.

A small, 40°, beam angle is the perfect replacement for legacy 2 mm to 5 mm through-hole IR LEDs, and the broadest beam angle, 130°, is ideal for flood illumination that is more common in security applications. Whether for biometric applications or monitoring for security, this latest generation of IR LEDs supports ongoing industry development and reduces time to market.

The IR SST products are industry standard 3535 surface-mount packages with low thermal resistance and are easy drop-in replacements. All Luminus IR SST emitters are rated as "Risk-Free" for eye safety according to the IEC Photo-biological Test (IEC/EN 62471 standard). ■

Lumileds IR Family for Cost-Conscious High-Power Applications

Lumileds introduced the Luxeon IR 2720 Line, high power emitters that set the standard for abundant radiant power delivered in an industry standard package for seamless integration in existing designs. The emitters provide high radiant power of up to 1,300 mW at 940 nm or 1,250 mW at 850 nm wavelength and feature high efficacy and a popular 120° beam angle. The 2.75x2.0 mm LEDs are undomed and especially useful for applications with package height limitations that prevent the use of domed solutions. The emitters address a wide array of cost-conscious infrared applications from surveillance and machine vision to iris scanning and health monitors.

Lumileds introduced the Luxeon IR 2720 Line, high power emitters that set the standard for abundant radiant power delivered in an industry standard package for seamless integration in existing designs

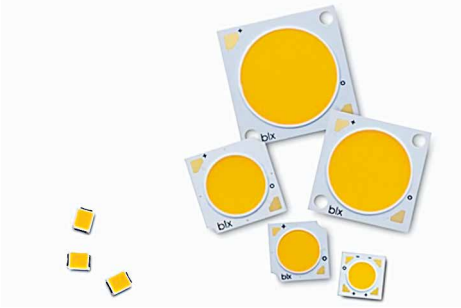
"Infrared LED uses such as CCTV cameras and machine vision are especially cost sensitive markets, so high performance emitters with high reliability are very much in demand," said Ryan Dong, Product Manager at Lumileds. The Luxeon IR 2720 package enables drop-in upgrades in applications that require high punch, long range and high

uniformity including positioning and depth measurement, and industrial automation. The state-of-the-art thermal resistance package (4°C/W) effectively solves thermal challenges and ensures system reliability which has been thoroughly tested during the Lumileds extensive qualification process.

The Luxeon IR 2720 Line of 940 nm emitters address such applications as biometric identification, military and law enforcement, and traffic and railroad signaling applications. The 850 nm emitters are workhorses for machine vision and CCTV cameras. ■

Bridgelux Introduces Thrive - Human Centric Light Spectrum Mimicking Sunlight

Bridgelux announced Thrive, a family of white point options for surface mount devices (SMD), V Series™, Vero® Series and Vesta® Series chip-on-board (COB) products designed to closely mimic the sun and provide a new class of full spectrum, human centric light emitting diode (LED) white point solutions.



Thrive is the name for Bridgelux's sunlight mimicking white LED versions that are available for SMD, V Series™, Vero® Series and Vesta® Series product lines

Thrive offers:

- Full spectrum 95 CRI light quality with similar efficacy compared to 90 CRI light sources
- Excellent CRI and TM30 metrics with R1 to R15 greater than 92, Rf 96-98 and Rg 99-102
- Lower Circadian Action Factor (CAF) and Melanopic Ratios (MR) in warm white color points, and higher CAF and MR values in neutral and cool white color points, which are optimized for human well-being
- 2700 K, 3000 K, 4000 K, 5000 K, 5700 K, 6500 K CCT options

Using proprietary chip, phosphor and manufacturing technologies, Thrive closely mimics the spectra of the sun without violet light augmentation. Thrive produces lower blue light intensity at shorter wavelengths and delivers a smoother spectrum over the visual wavelength range, enabling a close spectral match to sunlight.

"We believe Thrive white points may be effective in a variety of applications including hospitals, residential, offices, education, and museums. So many of us spend a large portion of our time indoors without the benefit of natural light. Thrive improves our indoor experiences under artificial lighting with its vivid color rendering and close match to the natural light provided by the sun," said Dr. Brian Cumpston, Vice President of Solutions at Bridgelux. "With the ongoing awareness and interest in human centric lighting solutions, we believe Thrive will assist lighting manufacturers to incorporate circadian features into their products as the lighting market continues to evolve."

Thrive white points are now available for sampling on SMD 2835 1W 9V and V Series 10C. Additional Thrive SMD and COB product options will be available for sampling in Q2. ■

Lumileds Boosts Cost Effectiveness & Efficiency of Luxeon 2835E

Lumileds introduced a new version of the Luxeon 2835E 9V LED specifically optimized for the typical drive current of retrofit lamps and downlights, 100 mA. Lamp designers will achieve a 5% boost in efficacy over the 60 mA LED when driven at the same current, leading to more efficient retrofit lamps including A19, PAR and B11 lamps. Forward voltage drops by 4% as well. The new 2700 K / 80 CRI Luxeon 2835E 9V produces 118 lm and achieves 127 lm/W at 9.3 V (versus 120 lm/W at 9.7 V).

At a typical drive current of 100 mA, Luxeon 2835E 9V LED is 5% more efficient at even lower forward voltage than the 60 mA part

"The Luxeon 2835E is extremely popular for retrofit lamps because of its high efficiency and compact package. Now with a drive current closer to operating conditions, customers get the most relevant spec for output and efficacy," said Mei Yi, Product Manager of Mid Power Products at Lumileds. Unlike competing products, the Luxeon 2835E also can be driven at up to 150 mA, with a junction temperature of 125°C for reduced LED count in compact designs.

The Luxeon 2835E LEDs are available in a wide range of color temperatures and minimum CRI of 70 to 90. The LEDs are hot color targeted, ensuring the color remains inside ANSI bin specifications at typical operating conditions. Design kits are available to meet to 3-, 4- and 5-step MacAdam ellipse color consistency. ■

Lumitronix Introduces LED Module Series for Ledil Daisy Optics

The LED specialist Lumitronix from Baden-Württemberg has produced three special LED modules which are compatible with the lenses of the Daisy series by Ledil. As Ledil's official distributor, the Swabian company was able to develop the modules in close cooperation with the Finnish optics manufacturer.

Lumitronix's new tunable white LED modules for the LEDiL Daisy optics series uses 757 series Nichia or SSC SunLike LEDs for unprecedented light quality

Daisy is a linear solution for office and workplace lighting with a seamless and glare-free cover in combination with effective lenses. The special optics are available with four, seven and 28 lenses each and the corresponding shades in black and white. A particularly practical feature is that the plastic shades can be clicked onto the lenses.

The Tunable White LED modules from Lumitronix were manufactured in the lengths 156x28 mm, 274x28 mm and 559x28 mm and were equipped with 16, 28 and 56 LEDs of the 757 series from world market leader Nichia in the color temperatures 2700 and 4000 K respectively. Together with the rod lenses of Ledil's Daisy family, the modules are first and foremost suitable for use in office and workplace luminaires. They can also be used in public spaces and halls. Furthermore, variants of the modules can be manufactured with the full spectrum LEDs Optisolis (Nichia) and SunLike (Seoul Semiconductor/Toshiba Materials) on request. ■

Tridonic "Light You Can Stick Anywhere" - Efficient Light for Profile and Linear Luminaires

With its flexible, linear constant-current LLE FLEX CC advanced modules Tridonic offers efficient LED modules from the reel which are easy to install thanks to 3M adhesive tape, and take up little space in the warehouse. AVX terminals or solder points can be used for simple wiring with no shadows.

Tridonic's flexible LLE FLEX CC ADV LED modules offer greater design freedom and deliver homogenous light of high quality in all available color temperatures

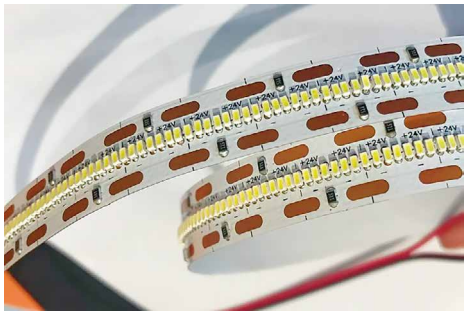
The LEDs are on a flexible, 14 mm wide and 25 m long reel which can be split every 140 mm so the right length can be selected for different profile and linear luminaires. Each 140 mm segment contains 16 LEDs that produce a homogeneous light. With feed from either end you can create a uniform line of light up to 3 meters in length with no obvious light points. Extremely durable and weather-resistant adhesive tape on the back of the LED modules makes it easier to install them on profile and linear luminaires made of extruded aluminum or steel.

High luminous flux, high module efficacy: The flexible, linear LLE FLEX CC ADV LED modules have a typical luminous flux of 1250 lm and achieve a module efficiency of up to 209 lm/W. They are ideal especially as part of an LED system solution comprising the linear module and matching SELV LED driver. In this configuration they achieve a system efficiency of up to 182 lm/W.
The LED modules are available with color temperatures of 2700 K, 3000 K and 4000 K, in each case with Ra > 80 and Ra > 90. Thanks to narrow color tolerances (MacAdam 3), the right quality of light can be achieved for the relevant location, such as offices, reception areas or corridors.

The reels with the flexible light strips require little space, which makes storage easier. The manufacturer specifies a life of 60,000 hours and provides a five-year guarantee. ■

LUXX Light Technology Releases World's First 700 LEDs per Meter LED Strip Light

LUXX Light Technology announced the launch of a new 700 LEDs per meter tape light. Available in single colors and color temperatures ranging from 2700-6500 K this new series comes in at only 0.47" wide and less than 0.04" tall, also boosts 90 CRI, and delivers consistent ultra-bright light quality.



Using 700 LEDs per meter offers the advantage of a linear lighting effect and, because they are under-driven, an increased lifetime

"Our new 700 SMD LEDs series emits minimal heat while generating a total linear lighting effect that is crisp and clear", said Andreas Weyer, Managing Partner at LUXX Light Technology. "The strips are significantly under-driven to extend the LEDs life up to 70,000 hours and you can still experience total linear illumination due to the high count of LEDs per meter." ■

Nedap Introduces Luxon IoT Node for Outdoor Lighting

Nedap is extending its Luxon IoT Node portfolio with a version developed for smart and wireless outdoor lighting control: The Luxon IoT Node Outdoor. The compact Luxon IoT Node Outdoor fits inside all LED fixtures using a standardized Zhaga/NEMA connector. This makes it very simple to unlock the full savings potential of LED technology.

Nedap's Luxon IoT Node Outdoor is designed according to the Zhaga/NEMA specifications

Features:

- Cost-effective, to create internet connected and wirelessly controlled luminaires
- Philips SR, Osram, Dexal, DALI and -V ready
- Small dimensions
- Standard Zhaga interface
- Luxon Cloud compatible
- Easy to install
- Integrated lux and temperature sensor
- OTA programming

Nedap Luxon Cloud features:

- Time, daylight, motion and dim control
- Direct motion sensor control
- Flexible group assigning
- Multi-site management
- Management reports
- Calculated energy logging

With the introduction of the outdoor node, Nedap is taking the next step in connectivity for the lighting market. Jeroen Somsen, managing director at Nedap Light Controls: "We've seen many solutions that focus on office environments and homes, but for industrial applications with outdoor locations, development has lagged behind. It's a missed opportunity, because this is precisely where a lot of energy is consumed, and where maintenance is a challenge. With the Luxon IoT Node Outdoor, we're offering a solution through connectivity that will have a

significant impact on energy consumption and operational costs, especially in demanding environments. While a LED retrofit halves energy consumption, connected lighting reduces energy consumption by as much as 75 percent."

EPtronics - Programmable LP25W & LP40W Rev C LED Drivers

EPtronics is delighted to announce its newest generation LP Series of programmable constant current LED drivers. The LP25W and LP40W Rev C Series are the latest flicker-free, best-in-class drivers included in UL's Class P LED Driver Program. This UL listing program can save significant time and costs for LED luminaire manufacturers, allowing them to quickly substitute existing LED drivers with pre-approved EPtronics drivers without the need for UL recertification.

EPtronics' latest update of the LP-series drivers includes improved dim-to-1% and dim-to-zero performance

Some of the latest LP25W and LP40W Rev C features include:

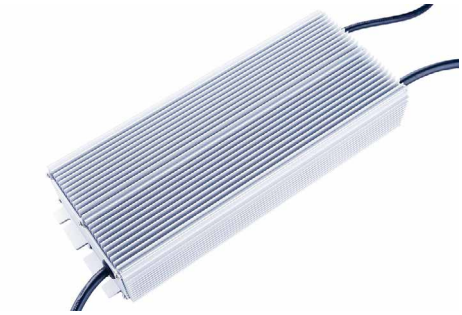
- Upgraded Dim-to-1% and Dim-to-Zero performance
- New Soft-Start option that enables fade to full-on startup dimming
- Faster startup time to any dim level (<500 ms, meets CA Title 24)
- Introducing new Constant Lumen Output Maintenance capability
- Added driver temperature logging
- 2x faster firmware programming

LP Series drivers can be pre-programmed to meet customer requirements during manufacture and re-programmed in the field using EPtronics' EP-PRG-01 USB Interface Programming Tool. In addition, the optional EP-CRADLE-01 programming cradle allows OEMs to reduce SKUs and program LP Series drivers on their own assembly lines, accelerating time to market.

EPtronics, a leading manufacturer of solid-state lighting power products, offers the broadest selection of UL listed and recognized off-the-shelf LED drivers. Our US-engineered products ensure exceptional performance and reliability to satisfy your technical requirements. All EPtronics products are protected by a standard 5-year limited product warranty.

40-720 W High-Power LED Drivers with 97% Efficiency & 660 V Input

The "ICE" family of LED drivers from GWP-Powerland Technology Inc., a Division of FSP-Powerland, is an ultra-high-efficiency LED driver series targeted toward outdoor lighting like horticulture, fishing, sports, and other outdoor LED applications. The output programmability and wire controllability through optional Bluetooth or ZigBee makes the system solution very flexible.



GWP's ICE LED driver family is an ultra-high-efficiency LED driver series targeted toward outdoor LED applications

Summary of Powerland's "ICE" family of LED drivers features:

- Isolated dimming signals
- Bluetooth and ZigBee versions optional
- Compatible with 0 (0.05)-10 V, PWM, external resistor, clock dimming
- Compatible with DMX (upon request), ultra-deep dimming down to 0.5%
- Ultra-high input voltage up to 660 Vac
  - 70,000 hours lifetime at 75°C Tcase
  - 7 years warranty at 75°C Tcase
- Min. operating temperature @ -40°C
- Safety design: UL8750 & EN61347-2-13
- Surge voltage: L-N 5.5 kV, L/N-Earth 11 kV
- EMC according to FCC Part 15 Class A
- Lightning, OVP, SCP, OTP & Open Circuit Protection

Powerland's patented energy conversion technology boosts the efficiency to an unprecedented level at 97%. Plus, the driver has a long-life time at 70,000 hours at the operating temperature of 75°C. These LED drivers are built with an ingress grade at IP67, and all-around protections such as short circuit, over voltage, over temperature, and 5.5kV/11kV lightning protections.

Specifically designed for North America's high AC input applications, the "ICE" family of drivers features various input options with 108~305 Vac, 240~382 Vac, 277~460 Vac, and 305~660 Vac.

The ICE-305 series has an output power up to 720 W. With a 108~305 Vac input voltage range, it is one of the most versatile drivers in its class, with both constant current and constant voltage mode programmed through either wire or optional Bluetooth/ZigBee wireless connections. It is the only driver series in the world that can serve either constant current or constant voltage by the same unit.

The ICE-347 series covers input voltages up to 382 Vac. It has an inherent unprecedented efficiency - as high as 97%. With a

240x123x54 mm dimension and 2.9 kg weight, it is the smallest and lightest driver for 347 Vac input applications.

The ICE-400 series is designed and manufactured for EU applications. With 600/720 W output and 277~460 Vac input capability, it also features the highest efficiency at 96% in its class at 400 Vac input applications.

The ICE-600 series is featured with 305~660 Vac input and power rating of 600 or 800 W. It is the only series in the world that is capable of operating in 600 VAC applications. This capability ensures unparalleled reliability and robust endurance in the most rigorous grid situations, comparing with other state-of-the-art 480 Vac LED drivers. ■

Tridonic Adds Casambi Ready RF Modules and Sensors to basicDIM

For Bluetooth-based communication between luminaires Tridonic is launching two new Casambi Ready wireless modules in the basicDIM Wireless portfolio. They can be easily and flexibly integrated into existing systems and, with suitable sensors, can offer considerable potential energy savings. It is also possible for the lighting system to be individually adapted.

Two new Casambi Ready wireless modules and a sensor have been added to Tridonic's basicDIM Wireless portfolio, making lighting system upgrades child's play

Thanks to their small size, both the passive basicDIM Wireless module and the constant-voltage basicDIM Wireless module can be easily integrated in the lighting installation. They automatically establish a communication network with up to 127 light points. The luminaires in this network can then be wirelessly switched and dimmed and also assigned to groups. Demand-oriented lighting scenes are also easy to set up.

Supply via DALI or 12-24V DC
Measuring 40.4 x 36.3 x 14.0 mm, the passive module can be comfortably integrated in luminaires that are not yet equipped with basicDIM Wireless drivers. It can be supplied with power via the standard DALI line or directly from the new premium (PRE) po4a DALI driver. Communication takes place via Bluetooth. This means that the wireless module connects the luminaires without the need for an external gateway. It can also be linked to a basicDIM Wireless sensor to include presence and ambient light in network control.

The basicDIM Wireless PWM CV-4CH module is supplied with 12-24V DC and measures 72.6 x 30 x 18 mm. Up to four channels can be switched and dimmed via Bluetooth - for example, four linear LLE FLEX strips or even completely different constant-voltage LED modules. With this module, existing LED strips can be easily dimmed without the need for additional DALI lines or drivers. The maximum output current is 6 A, which can be split in any way among the four channels.

The modules can control anything from a single luminaire to a lighting system with up to 127 light points, for example in offices or classrooms. Control is intuitive via the free 4remote BT app on an Android or iOS smartphone. The app is available in the Google Play Store or the Apple App Store and supports wireless firmware updates.

The two new wireless modules together with the 5DP basicDIM Wireless sensor round off the portfolio from Tridonic. Casambi Ready control technology allows for versatile interaction with all the luminaires in a room, via either the app or the user interface, without any additional wiring. The wireless communication network is established automatically. ■

Infineon XDPL8221 for Advanced, Smart and Connected LED Driver

The emerging trend of smart lighting and Internet of Things, requires a new generation of LED drivers. Infineon Technologies AG introduces the new member of its XDP™ LED series, the XDPL8221 for cost-effective dual-stage drivers with advanced features.

Infineon's XDPL8221 combines several advanced functions. The result is a versatile, high performance LED driver

Features:
- Supports AC and DC Input
- Nominal input voltage range 100 VAC - 277 VAC or 127 VDC - 430 VDC
- Reference board efficiency > 90%
- Power factor > 0.9 and THD < 15% over wide load range
- UART interface and command set
- Standby power < 100mW
- Temperature guard with adaptive thermal management with internal and/or external sensor
- Digital control selects automatically best mode of operation, depending on actual requirements:
  - QRM (quasi-resonant mode)
  - DCM (discontinuous conduction mode)
  - ABM (active burst mode)
- Tunable, digital parameters
- Configurable brown-out and brown-in protections
- Error conditions such as undervoltage, overvoltage, open load and output shorted are monitored and protected

Benefits:
- The XDPL8221 enables the design of high performance and innovative advanced LED driver for connected lighting with small effort
- Reduced BoM minimizes system cost and increases flexibility
- High reliability features improve long lifetime of the driver
- Fast design cycle reduces time to market and efforts for value products
- Supply chain efficiency optimizes stock keeping and enables high flexibility
- Real time operating parameters digitally available by UART interface
- Dimming control numerically precise through UART commands
- Target Applications:
- Flicker-free LED driver for indoor or outdoor applications
- Multi-mode LED driver for connected lighting
- Wired or wireless connected LED driver

The XDPL8221 combines advanced functions, such as multi control featuring constant voltage, constant current and limited power as configurable operating parameters. The result is a versatile, high performance LED driver.

The performance of the XDPL8221 helps to design more efficient devices. This driver IC supports full functionality for both AC and DC input in the nominal input voltage range of 100 V AC to 277 V AC or 127 V DC to 430 V DC. Depending on the actual situation, the built-in digital control selects the best mode of operation. It can switch between quasi-resonant, discontinuous conduction or active burst modes.

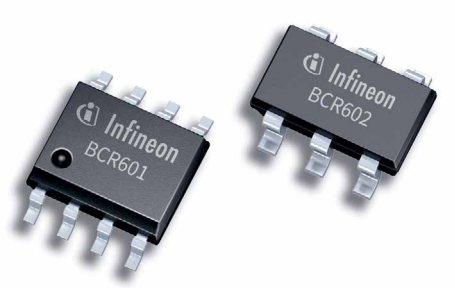
The XDPL8221 UART interface with a command set enables control of the functions of the device and provides status information. This enables numerically exchanged real-time data. This data can be used for monitoring or additional local control functions.

This driver IC can be dimmed flicker free below one percent, while the current is still regulated with a high accuracy. The chip also offers a dim-to-off function to keep the device in a standby mode when the light is off with a low standby power (less than 100 mW, depending on driver design).

Reduced bill of materials (BOM) and increased flexibility minimize the overall system cost. The XDPL8221 comes in a DSO-16 package and, with a wide tool support, it is easy to design-in. This accelerates the design cycle and shortens time-to-market. ■

Infineon - New 60 V General Lighting Linear LED Controller ICs

With the BCR601 and BCR602 Infineon Technologies AG introduces two new members of its successful BCR linear LED controller IC portfolio. The BCR601 features an innovative voltage feedback to the primary side also known as "active headroom control" (AHC), enabling cost- and power-effective LED driver applications. The BCR602, on the other hand, targets dimmable LED applications such as light engines, modules and strips. Its wide voltage range of up to 60 V makes it an ideal fit for 48 V designs and DC/DC grids.



Infineon's new linear LED controller ICs, BCR601 and BCR602, operate with an external driver transistor; either an NPN bipolar transistor or an N-channel MOSFET to support a wide LED current and power range

Target applications:
- LED light engines/modules
- LED replacement lamps

Advantages:
- Low BOM count
- Lower assembly cost
- Smaller form factor
- Higher reliability due to less parts and soldering joints

The supply voltage of the LED controller ICs ranges from 8 V to 60 V up to the SELV limit. Both, BCR601 and BCR602, operate with an external driver transistor, either an NPN bipolar transistors or an N-channel MOSFET to support a wide LED current and power range. With the ICs, the LED current can be adjusted by resistors as well as dimmed analog, while the BCR602 also accepts digital PWM up to 3.5 kHz and combined dimming. BCR601 and BCR602 represent an inherent AC ripple suppression, thus driving a constantly stable LED current to prevent light flicker and provide high light quality.

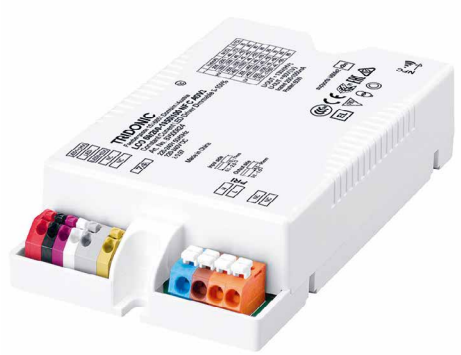
The AHC of the BCR601 allows controlling the output voltage of the primary side converter such as the XDPL8218 flyback controller from Infineon. This architecture helps a linear LED controller to achieve maximum system efficiency by actively adjusting the AC/DC feedback loop to set minimum voltage headroom.

Adjusting the minimum necessary voltage across the pass transistor optimizes system efficiency which can normally only be achieved by secondary switched mode solutions. An optimized efficiency reduces component temperatures and stress. Further advantage of this solution is reduced EMI compared to switched mode supplies in combination with a low BOM. Additionally, the BCR601 features an adjustable over-voltage protection to prevent any damage to the LEDs.

Both ICs also offer embedded hot-plug protection. This allows connecting or disconnecting the LED load without power down protecting the LEDs from electrical over-stress events. The over-temperature protection reduces the LED current by 30 percent of the nominal current as soon as the junction temperature exceeds the defined threshold. The LED controller ICs resume regular operation as soon as the temperature drops below the hysteresis. ■

Tridonic Announces Third-Generation Outdoor Drivers Now Having NFC Interface

Third-generation outdoor drivers from the excite (EXC) and advanced (ADV) series by Tridonic are now available, all with NFC interface. The dimmable control gear elements for the luminaire fixture are available in various wattages and also, if required, with matching LED modules.



The third generation of outdoor drivers in the EXC and ADV series now features an NFC (Near Field Communication) interface to save programming time in luminaire production

The third generation of outdoor drivers in the EXC and ADV series is the first to feature an NFC (Near Field Communication) interface. NFC technology saves programming time in luminaire production and allows units with up to 20 drivers to be configured in a single work step. In addition, both series are equipped with ready2mains and U6Me2 interfaces, while the EXC3 series also comes with one4all. Changes to the settings can be made even after installation via the NFC interface, ready2mains or DALI-2 (EXC3).

Variable setting of the output current:
The control gear elements for luminaires in protection classes I and II are available in different output powers and cover a wide range of applications with application-oriented operating windows. EXC3 drivers are available with 14, 24, 40, 60, 90, 135 and 200 W output power, ADV3 drivers with 14, 24, 40 and 60 W output power. The output current can be set between 100 and 500 mA for the 14 W version of the outdoor drivers and between 200 and 1050 mA for all others. There are several configuration options: wirelessly via NFC using Tridonic's companionSUITE software or with the ready2mains programmer. In the EXC series, programming is also possible via DALI-2 using masterCONFIGURATOR.

The devices are dimmable from 5 to 100% via the mains voltage (inputDIM) and offer application-specific light levels. The mains voltage is selected on the basis of defined minimum and maximum dimming levels within the voltage range of 170 and 250 V AC. The chronoSTEP2 function can also be used to define different dimming levels and day segments. In this way, the brightness can be adjusted by the program to the actual demand and reduced, for example, at night or during less frequented times.

Improved protection for drivers and LED modules:
The outdoor drivers complete even demanding tasks in outdoor and industrial lighting. In addition to the high safety standards of its predecessors, the new generation offers further special protection mechanisms for the connected LED modules. The Intelligent Voltage Guard Plus (IVG+) function is triggered if the mains voltage deviates from the defined nominal voltage range. In the undervoltage range, the driver dims the LED module by 10 percent, and switches it off below 80 V. The module is also switched off at voltages above 280 V. In both cases, the driver automatically restarts when a certain threshold is reached. IVG+ has priority over an inputDIM that is activated at the same time. Protection against thermal damage is provided by external temperature management (ETM) via a temperature sensor (NTC). Here, too, the brightness is reduced or the device switched off if predefined desired values are exceeded.

Additional protective functions contribute to the safety of the long-life drivers themselves. These include high overvoltage protection up to 10 kV as well as protection against overtemperature, short circuit, overload and open circuit. EXC3 drivers with the higher wattages of 90 W, 135 W and 200 W can withstand up to 20 overvoltage events in operation.

Efficient street and industrial lighting:
The outdoor drivers, which have an IP 20 degree of protection, are used mainly in street and industrial lighting. Low standby losses of fewer than 0.16 W and a high degree of efficiency of up to 95% (at 200 W) make the drivers experts at energy saving.

The 2V-Out function ensures efficient operation. It maps out two different, optimized operating windows, created via two channels: high-voltage for LED modules with high voltage requirements, low-voltage for LED modules with lower voltage requirements. This ensures the best possible operating efficiency in each case.

The devices have integrated DC detection and are also suitable for emergency escape lighting systems in accordance with EN 50172. The manufacturer ensures a nominal life time of 100,000 hours and an 8-year guarantee. ■

Inventronics Expands Family of Controls-Ready, High Input Voltage LED Drivers

Inventronics has announced the expansion of the ESD family of Controls-Ready, high input voltage LED drivers to include models delivering a full 480W at a wide output current range between 1.5-10.0 A. The new ESD-480SxxxDT series operates over a 249-528 Vac input range making it ideal for a multitude of projects in varying geographical locations. It provides absolute cost savings with full-load efficiency up to 95% and eliminates the need for a step-down transformer within the lighting fixture.

Inventronics' high voltage input driver delivers exceptional full-load efficiency and is controls ready providing different dimming options

Features:
- Programmable
- Controls-Ready:
  - Dim-to-Off with Low Standby Power
  - Always-On Auxiliary Power 12 V / 200 mA
- Multiple Dimming Functionalities:
  - 0-10 V, PWM, Multiple Timers
- Input Surge Protection:
  - 6 kV DM, 10 kV CM
- Output Lumen Compensation
- SELV Output
- IP67 and UL Dry/Damp/Wet Location
- TYPE HL, for use in Class I, Division 2 Hazardous (Classified) Location
- 5 Year Warranty

The ESD-480SxxxDT drivers are equipped with Controls-Ready features which provide a 12 V / 200 mA auxiliary output and dim-to-off capability with ≤0.5 W standby power consumption. The benefits of these features to OEMs and lighting designers are decreased installation space and reduced fixture costs by eliminating the need for a secondary power supply and an AC switch or relay to turn the drivers on/off. For more energy savings, they provide dimming functionalities such as 0-10V, PWM and

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3 timer modes, making them more versatile than traditional LED drivers and allowing easy integration into smart lighting applications.

The ESD-480SxxxDT supplies 6 kV line-to-line and 10 kV line-to-earth surge protection which provides a stable and reliable performance, regardless of the environmental factors. They are IP67 rated, TYPE HL drivers making them a rugged option for harsh indoor and outdoor lighting applications including sports arena, horticultural, port and high mast lighting. They feature over-voltage, short-circuit, and a self-recovering internal and external over-temperature protection while also including output lumen compensation and thermal sensing for LED modules. This results in less maintenance and no power recycling.

This new series is approved to UL, FCC and CE standards. Production quantities of the ESD-480SxxxDT series are available now.

TE's LUMAWISE Endurance S - New, Compact & Zhaga Book 18 Compatibility

TE Connectivity (TE), a world leader in connectivity and sensors, has introduced a new compact connectivity solution that matches a new standardized interface between an outdoor LED luminaire and a sensing/communication module that sits on the outside of the luminaire. TE´s LUMAWISE Endurance S connector system consists of a standardized interface connection according Zhaga Book 18 and includes a receptacle to be mounted on the luminary and a base-and dome combination to function as enclosure for the control-electronics.

TE enables luminaires without limitations with LUMAWISE Endurance S in a 40 mm and 80 mm version

With this family of components, it becomes possible to create a luminary with sockets that allows compatible sensing and/or communication modules that can easily be removed and replaced.

Sensing and communication modules typically provide sensory inputs to the LED drivers and communicate with other luminaries in a network.

The new connector receptacle uses a single integrated gasket to seal the luminary and the module with just one seal. Internal wiring is connected by well-known poke-in wire connection. An impact resistant sealing cap can be used when no module is placed.

The electronics for the control system can be housed in a base and dome combination that comes in two diameters (40 mm and 80 mm) and for the 40 mm dome 2 different heights are available, for the 8 0mm base even 3 different heights are available. All domes come in a transparent or a dark-smoke color and other colors are on request. The base-and-dome combinations are IP65 and IP66 sealed and have impact rating up to IK09.

The sense and control modules can be mounted in any orientation, top, side or downward facing with no limitation to the sealing, and due to the simple twist-lock-feature modules can be exchanged in a few seconds.

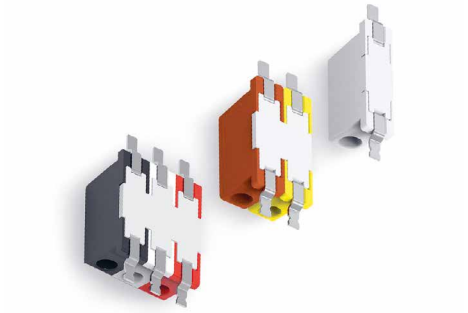
LUMAWISE Endurance S was co-developed with several partners to ensure a complete system is available, including application specific drivers and control nodes. TE also collaborated with the Zhaga Consortium, a global lighting-industry organization that standardizes components of LED luminaires.

Jeroen Iedema, product manager at TE Connectivity said, "The development of this product-line was a collaborative process with the Zhaga Consortium, in which we were able to apply our extensive experience and expertise in street light connectors. The focus of developing the new specification, Book 18, was to demonstrate the potential of new architecture and new functionalities that can create value for developers, installers and users of outdoor lighting and future city management systems.

"The standardized interface defined in Zhaga Book 18 enables the installation of future-proofed outdoor LED luminaires, which can be easily upgraded with smart communication and sensing capabilities," said Dee Denteneer, secretary general of Zhaga. "We are pleased to see that member companies, including TE, are already using the specification to develop products that will stimulate the market for smart outdoor LED luminaires."

TE ITB - Releasable Poke-In Connectors for LED Lighting

TE Connectivity (TE), a world leader in connectivity and sensors, has unveiled BUCHANAN WireMate ITB (Inverted Thru-Board). These wire-to-board connectors are for use in linear and circular LED modules found in all sorts of commercial and industrial lighting systems.



TE's ITB releasable poke-in connectors for a vast range of LED lighting applications provide extra flexibility for reuse and wire replacement

With their easy-to-use poke-in and wire release features, the new connectors help shorten installation times and provide extra flexibility for reuse and wire replacement. No crimping or soldering is needed when attaching wires; once inserted, wires are strongly retained and will not inadvertently pull out. A robust integral release feature allows rework, if required.

In addition, the reduced profile of the BUCHANAN WireMate connectors takes only 2 mm in height above the PCB top surface while horizontal wire insertion minimizes space usage beneath the PCB.

"These new connectors are particularly versatile," says Product Manager Asam Jiang. "Each one can accommodate any combination of solid and stranded wires, ranging in size from 22-18 AWG (0.35-0.75 mm^2). They conform to the UL 1977 standard for component connectors for use in data, signal, control and power applications."

The Buchanan WireMate ITB wire-to-board connectors have a maximum voltage rating of 320 V and a current rating of 6 A (for 18AWG wiring) or 5 A (20 and 22AWG). They are molded in a high-temperature-resistant nylon (PPA) casing that withstands high temperature SMT soldering temperatures. The connectors are modular in design, available for up to five wire connections and in different colors to help installers avoid mistakes when inserting wires. ■

Lighting Analysts Releases Luxiflux-Zonal - Web-Based Interior Lighting Estimator Tool

Lighting Analysts, a global leader in illumination engineering software, is pleased to announce the release of our latest web-based software, Luxiflux-Zonal, the anticipated new responsive design, interior lighting estimator tool for product manufacturer's websites. This software utilizes server-side, AWS-hosted architecture opening the door for additional new web-based software development. The ground-up responsive design provides an excellent user experience for mobile users (iOS and Android) as well as traditional desktop.

Luxiflux-Zonal is an anticipated new responsive design, interior lighting estimator tool for product manufacturer's websites

Luxiflux-Zonal is a zonal cavity calculation tool that allows browsing customers to quickly estimate the illuminance level, number of luminaires, power density, and a lighting layout for a simple rectangular space. "Typically, first time visitors go through the input sections left to right. Once familiar with the software's operation the user can skip around and obtain results in seconds!", says David Speer, Co-Founder and Director of Business Development. "The software computes instantly when it has enough input." A customizable one-page output can be printed from the web browser or emailed. Luxiflux-Zonal uses XML based input and output which gives webmasters flexibility in programming appearance and function. It is very easy to customize the screen appearance with a company logo and brand colors which allows the tool to integrate seamlessly manufacturer websites. ■

New Kinglumi Downlight Solution Milo™ for Infinite Possibilities

Kinglumi(K&L), a design-and-manufacture lighting company, announced that it has launched Milo™ downlight, a new line of high-performance portfolio dedicated to architectural lighting segment. With complete modular design concept and equipped with the latest MultiCCT and MultiPower technology innovation, it simply configures multiple combinations to satisfy diversified customer's requirements. This system unveils a special combination of unobtrusive light sourcing with various mounting capabilities, superior performance, high-quality materials and best in class LED technology and drivers.

Kinglumi's new Milo™ offers multiple possibilities because of its modular concept

Endless Possibilities:
Designed as a family of architectural low profile recessed, trimless, surface and pendant mounted luminaires common in quality, efficiency and aperture size. Milo, available in 6 different aperture sizes (ϕ100, ϕ125, ϕ150, ϕ200, ϕ250, ϕ300. unit in mm), and various reflectors (specular/ high-gloss mirror, silver, black, gold, white) options to create infinite possibilities for comfortable ambience.

High Flexibility & Minimize Inventory:
Milo was enabled with the latest MultiCCT technology (3-CCT or tunable white, 1-CCT by request), and MultiPower Tech (Wattage selectable), it's very flexible and easily tailored on-site. Also, the complete modular design in one system helps to minimize the inventory and short the time to projects.

Various Electronic Control Gear:
The fixture keeps its classic design with an external driver, which is not visible after installation, featuring low-level dimming and full 1.5 KV surge protection to ensure high-quality performance. Full range dimming capabilities offered (1-chanel: DALI-2 + Push-DIM, 1-10V, ON/OFF, Phase-cut), as well as the option to operate with 2-Channel drivers: Zigbee 3.0, DALI DT8, Bluetooth for intelligent lighting control.

Visual Comfort Light:
Equipped with dark light reflector for optimal glare control, Milo downlight with up to 30° cut-off angle and deep regression, minimizes the glare light and achieves a UGR 19 or UGR 22. Milo™ delivers a powerful, clean beam of light on high-end retail, airport, exhibition center, semi-outdoor, hospitals, hotels, offices, conference rooms, museum without calling attention to itself. MILO™ downlight, designed for future lighting and human centric lighting ready! ■

GlacialLight New Natural Sunlight GL-FL35-NL Architectural Floodlighting Series

GlacialLight, the LED lighting division of GlacialTech Inc., announces the natural sunlight GL-FL35-NL Architectural Floodlighting series. The new lighting fixtures use the SEOUL SunLike CoB to light up objects in their natural colors. The CRI is 97, as well as the CQS (Color Quality Scale) is up to 98. The color fidelity index (TM-30-15 Rf) and color gamut score (TM-30-15 Rg) are close to natural light.

Using SSC's SunLike COB LEDs in the GL-FL35-NL Architectural Floodlighting Series helps to improve the light experience for human health benefits

Features:

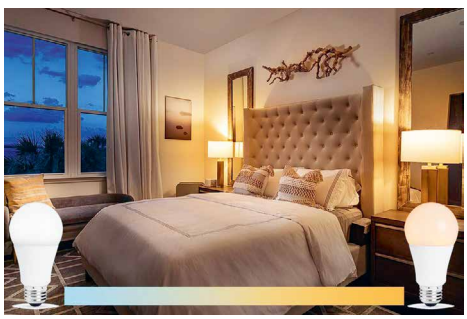
- High CRI is 97
- High CQS is 98
- TM-30-15 Rf is up to 97
- TM-30-15 Rg is up to 100
- 40°, 60° and 120° beam angle available
- Operating temperature range from -40°C to +45°C
- With lens hood accessory optional
- Corrosion-resistant aluminum Outdoor Stake Light Bracket optional

The GL-FL35-NL contents harmful blue light wavelength is significantly less than the conventional LED. The GL-FL35-NL features less glare and low diffusion reflection to protect vision. And also offers the optional lens hood accessory to suit aesthetics and reduce dazzle. The light of the GL-FL35-NL is smoother and gentler. It minimizes negative effects of conventional LED light sources.

The natural sunlight GL-FL35-NL series can improve the light experience for human health benefits. It closely matches the spectrum of natural sunlight and harmonizes light output with natural circadian rhythms. The GL-FL35-NL is suitable use in the museum, art gallery and indoor plant wall.

Healthe® SunTrac™ A19 Seamlessly Transitions Between GoodDay® & GoodNight® Spectrum

Healthe® launched of SunTrac™ A19, a product that combines engineered spectrums that have been optimized for both daytime and nighttime use into a single, dynamic, circadian lamp. Now, consumers can benefit from both the energy- enhancing GoodDay spectrum during the day and the sleep-promoting GoodNight spectrum at nighttime by simply installing this one bulb.



Healthe's SunTrac bulb can seamlessly transition between GoodDay, Afternoon and GoodNight spectra, delivering the right light at the right time of day

The SunTrac A19's three presets - GoodDay, Afternoon and GoodNight - mimic sunlight throughout the day, enhancing the wake-sleep cycle for improved health and well-being. Alternatively, users can take advantage of customizable settings to create the circadian cycle that is best for them and their daily schedule. Like the entire SunTrac line, the SunTrac A19 is designed to work seamlessly with a variety of control mechanisms, enabling consumers to enjoy the right light at the right time.

The SunTrac A19 can replace any E26, Edison-based bulb that is commonly used in standard lamps and fixtures.

"The unique benefit of this new product is that it can easily be tailored to the time of sunrise and sunset at each user's location," said Holly Prievo, Product Manager for the SunTrac A19. "Currently, dynamic lighting products can be complicated to use. Our A19 lamp provides users the choice of unmatched simplicity or virtually unlimited flexibility, depending on each user's individual preference. A user can easily sync all the lighting in their home to the cycle of the sun in a "set it and forget it" manner, letting our technology work for them 24-hours a day. Or a user can assert greater control on a room-to-room, fixture-to-fixture basis to reflect one's personalized schedule."

To enable spectral control capabilities, including spectral transitions and dimming, SunTrac A19 can be paired with the SunTrac Wireless Switch or SunTrac App, both of which can also be used with groups of other SunTrac products. Alternatively, the SunTrac A19 can be automatically synchronized with daylight cycle using the recently launched SunLync™, a GPS-enabled control device.

Healthe lighting products deliver circadian well-being for building occupants with their proprietary, engineered spectra. The GoodDay spectrum is blue-enriched at 480 nanometers (nm), the peak wavelength for the body's circadian sensitivity. GoodDay simulates the blue in natural sunlight, helps increase alertness and has the potential to improve productivity during the day. The GoodNight spectrum, which is blue-depleted at 480 nm, promotes the body's natural response to sunset and ultimately sleep.

Oculux Dim-to-Warm LED Track Luminaires by WAC Lighting

The new Oculux Dim-To-Warm architectural LED 120V track luminaires dim from a pure white 3000 K light temperature to an 1800 K incandescent ambient illumination. These superlative light levels are provided with a very high 95 CRI (color rendition index) to optimize tasks while creating a visually comfortable environment.

Oculux Dim-To-Warm architectural LED 120 V track luminaires combine LED performance quality with the warmth of incandescent light

The 11.5 Watt luminaires feature an integral driver and high output COB LEDs that deploy robust illumination, with 350° horizontal rotation and 90° vertical aiming. Oculux delivers up to 605 lumens with a CBCP (center beam candle power) of 1133.

Oculux Dim-To-Warm includes a 55° beam for flood optics film pre-installed and an interchangeable 30° film supplied for narrow flood or flood optics.

Four architectural finishes are offered: Black, Brushed Nickel, Dark Bronze and White.

The luminaires are compatible with WAC's H, L, J and J2 120-Volt track systems, as well as a wide range of popular tracks in the industry.

GlacialLight Announces New Natural Sunlight of GL-DLC06-35-NL Series

GlacialLight announces the natural sunlight GL-DLC06-35-NL and GL-DLC06DA-35-NL. The new lighting fixtures use the SEOUL SunLike CoB to light up objects in their natural colors. The CRI is 97, as well as the CQS is up to 98. The color fidelity index (TM-30-15 Rf) and color gamut score (TM-30-15 Rg) are close to natural light.

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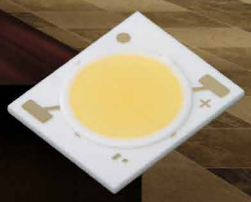
- Less disruptive circadian rhythm
- High color fidelity (Rf)
- Full color gamut (Rg)



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GlacialLight's latest downlights use SSC's SunLike CoBs to provide spectral power distribution and light appearance similar to sunlight

Features:

- CRI is 97
- CQS is 98
- TM-30-15 Rf is up to 97
- TM-30-15 Rg is up to 100
- With 90° beam angle
- WW (3000 K), NW (4000 K) and CW (5000 K) available
- GL-DLC06DA-35-NL with 3-in-1 dimming type available

The GL-DLC06-35-NL contents harmful blue light wavelength is significantly less than the conventional LED. The blue light will cause the vision decline rapidly and affect the sleep quality. The GL-DLC06-35-NL also features less glare and low diffusion reflection to protect vision. The light of the GL-DLC06-35-NL is smoother and gentler. It minimizes negative effects of conventional LED light sources. ■

LumenFocus Introduces New Versatile, Vapor-Tight EVT Linear Light

The EVT is a new vapor-tight offering from LumenFocus with a unique and innovative design. The lens and housing is one extruded piece, with gasketed end caps on both ends. This distinctive construction makes the EVT suitable for many commercial, industrial and institutional applications - including warehouses, manufacturing facilities, food processing facilities, stairwells and car washes.

The acrylic co-extruded lens and housing is (f1) rated, meaning it has met UL 746C requirements for water exposure or immersion. The (f1) rating also means the EVT is suitable for outdoor use.

LumenFocus' new vapor-tight EVT features easy mounting and long lifetime. They are easily upgradeable with DesignLights Consortium qualified versions available

The EVT is available in 2-foot, 4-foot and 8-foot lengths. Each length can be purchased in one of three lumen output packages, with performance ranging from 1,930 in the 2-foot "VL" package up to nearly 8,600 in the 8-foot "MD" package. Color temperature options are 3500K, 4000K and 5000 K. High performance LED boards are mounted on a pre-painted cold rolled steel tray. The EVT is UL approved and evaluated for daisy chaining.

Multiple hanging options are available for easy installation - including surface, chain/cable or pendant mounting. The mounting hardware is made of stainless steel.

An easy-to-use Snap-On Bracket comes standard on the EVT and is used for surface mounting. Selecting the Bracket Bail (SMBB) option allows for chain and cable mounting. The SMBB can be purchased with a 10- or 20-foot Quick Hang Cable Kit. An optional Safety Bail provides added security for the mounting.

An optional microwave occupancy sensor will help maximize energy savings. The sensor is also available with 0-10V dimming.

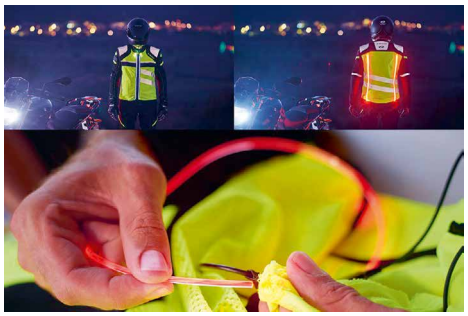
The EVT boasts a predicted L70 lifetime of greater than 100,000 calculated hours (72,000 reported hours). It comes with a five-year limited system warranty.

The EVT is made in America - every unit is manufactured out of LumenFocus' Henderson, NC facility. Specific EVT configurations are DesignLights Consortium qualified. These configurations can be viewed online at http://designlights.org. The EVT is UL 1598 listed for US and Canada and is suitable for wet locations. Other certifications include: IP65, IP66, NSF and RoHS.

The EVT utilizes LumenFocus' concept of Re-BoardABILITY: All LED boards and drivers are field replaceable in just a few minutes. As LED technology continues to rapidly improve in the future, customers may want to upgrade their boards and drivers to ensure their lights are as efficient as possible. LumenFocus luminaires are designed to allow customers easy access to remove and upgrade boards and drivers. This helps to ensure that customers don't get stuck with obsolete lighting equipment. ■

Luminous Motorbike Clothing for Enhanced Safety on the Road

Motorbike clothing manufacturer Held is cooperating with Osram to improve visibility on the road by including a range of models in its current collection that can be retrofitted with LED light modules from Osram. This move allows greater visibility and enhanced safety for motorcyclists during the night hours and in foggy and similar conditions.



The LED light modules ensure better visibility in darkness, fog and similar conditions. The light modules can be integrated quickly and simply into the clothing by the rider to suit requirements (Image Credits: Held)

"Integrating textile lighting in motorbike clothing offers a completely new way to enhance safety in road traffic. Together with Held, we have developed an effective solution especially for motorbike clothing," says Stefan Hofmann, Head of the Smart Textile Illumination business unit at Osram. Right on time for the motorbike season, Held is launching two motorbike jackets as well as a safety vest, which can be retrofitted simply by the motorcyclists themselves with actively illuminated light modules from Osram.

Passive protection in the form of reflector strips in clothing, for example, generally does not suffice on the roads during darkness and when visibility is poor. Jackets with

integrated lighting, on the other hand, do not require incident light from vehicle headlights or street lamps, rather offer active protection.

The Osram light modules, which are specially developed for two of Held's jackets and a safety vest, can be switched on easily before heading out on the motorbike by simply connecting a rechargeable battery pack. With no need for other manual settings, the light strips offer up to seven hours of active lighting in continuous operation (with a 4,000 mAh battery) with the LED light modules emitting white light at the front and red light at the back. The light modules can be integrated quickly and simply by the rider into the clothing through a fabric tube, and the battery charged with ease via a USB port.

Osram presented its light modules for textile lighting for the first time at the end of 2016, following a thorough endurance test under extreme conditions during an ice hockey game on Germany's tallest mountain. In the next step, Osram plans to combine light modules with sensor technology for example. This will in future allow various applications to be controlled using an app. Solutions that allow an emergency call to be triggered automatically in the event of an accident are also conceivable. ■

MIT Researchers - New Heat Conducting Polymer Films

Polymers are usually the go-to material for thermal insulation. Think of a silicone oven mitt, or a Styrofoam coffee cup, both manufactured from polymer materials that are excellent at trapping heat. Now MIT engineers have flipped the picture of the standard polymer insulator, by fabricating thin polymer films that conduct heat - an ability normally associated with metals. In experiments, they found the films, which are thinner than plastic wrap, conduct heat better than many metals, including steel and ceramic.

The team's results, published in the journal Nature Communications, may spur the development of polymer insulators as lightweight, flexible, and corrosion-resistant alternatives to traditional metal heat conductors, for applications ranging from heat dissipating materials in laptops and cellphones, to cooling elements in cars and refrigerators.

By mixing polymer powder in solution to generate a film that they then stretched, MIT researchers have changed polyethylene's microstructure, from spaghetti-like clumps of molecular chains (left), to straighter strands (right), allowing heat to conduct through the polymer, better than most metals

"We think this result is a step to stimulate the field," says Gang Chen, the Carl Richard Soderberg Professor of Power Engineering at MIT, and a senior co-author on the paper. "Our bigger vision is, these properties of polymers can create new applications and perhaps new industries, and may replace metals as heat exchangers."

In 2010, the team reported success in fabricating thin fibers of polyethylene that were 300 times more thermally conductive than normal polyethylene, and about as conductive as most metals. Their results, published in Nature Nanotechnology, drew the attention of various industries. It soon became clear that, in order for polymer conductors to work for any of these applications, the materials would have to be scaled up from ultrathin fibers (a single fiber measured one-hundredth of the diameter of a human hair) to more manageable films.

"At that time we said, rather than a single fiber, we can try to make a sheet," Chen says. "It turns out it was a very arduous process."

The researchers not only had to come up with a way to fabricate heat-conducting sheets of polymer, but they also had to custom-build an apparatus to test the material's heat conduction, as well as develop computer codes to analyze images of the material's microscopic structures.

In the end, the team was able to fabricate thin films of conducting polymer, starting with a commercial polyethylene powder. Normally, the microscopic structure of polyethylene and most polymers resembles a spaghetti-like tangle of molecular chains. Heat has a difficult time flowing through this jumbled mess, which explains a polymer's intrinsic insulating properties.

Xu and her colleagues looked for ways to untangle polyethylene's molecular knots, to form parallel chains along which heat can better conduct. To do this, they dissolved polyethylene powder in a solution that prompted the coiled chains to expand and untangle. A custom-built flow system further untangled the molecular chains, and spit out the solution onto a liquid-nitrogen-cooled plate to form a thick film, which was then placed on a roll-to-roll drawing machine that heated and stretched the film until it was thinner than plastic wrap.

The team then built an apparatus to test the film's heat conduction. While most polymers conduct heat at around 0.1 to 0.5 watts per meter per kelvin, Xu found the new polyethylene film measured around 60 watts per meter per kelvin. (Diamond, the best heat-conducting material, comes in at around 2,000 watts per meter per kelvin, while ceramic measures about 30, and steel, around 50.) As it turns out, the team's film is two orders of magnitude more thermally conductive than most polymers, and also more conductive than steel and ceramics.

To understand why these engineered polyethylene films have such an unusually high thermal conductivity, the team conducted X-ray scattering experiments at DoE's Advanced Photon Source (APS) at the Argonne National Laboratory.

"These experiments, at one of the world's most bright synchrotron X-ray facilities, allow us to see the nanoscopic details within the individual fibers that make up the stretched film," Jiang says.

By imaging the ultrathin films, the researchers observed that the films exhibiting better heat conduction consisted of nanofibers with less randomly coiled chains, versus those in common polymers, which resemble tangled spaghetti. Their observations could help researchers engineer polymer microstructures to efficiently conduct heat.

Going forward, the researchers are looking for ways to make even better polymer heat conductors, by both adjusting the fabrication process and experimenting with different types of polymers. Zhou points out that the team's polyethylene film conducts heat only along the length of the fibers that make up the film. Such a unidirectional heat conductor could be useful in carrying heat away in a specified direction, inside devices such as

laptops and other electronics. But ideally, he says the film should dissipate heat more effectively in any direction.

"If we have an isotropic polymer with good heat conductivity, then we can easily blend this material into a composite, and we can potentially replace a lot of conductive materials," Zhou says. "So we're looking into better heat conduction in all three dimensions." ■

Acknowledgements:
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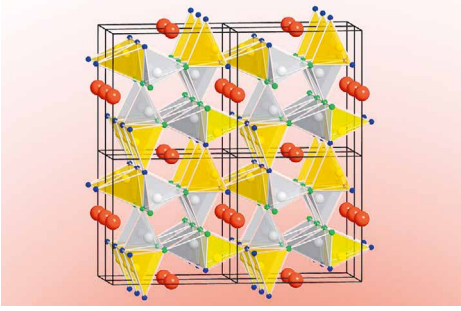
About the Authors:
Chen's co-authors include lead author Yanfei Xu, along with Daniel Kraemer, Bai Song, Jiawei Zhou, James Loomis, Jianjian Wang, Migda Li, Hadi Ghasemi, Xiaopeng Huang, and Xiaobo Li from MIT, and Zhang Jiang of Argonne National Laboratory.

Energy-Saving New Red LED Phosphor Developed at University of Innsbruck

The human eye is particularly sensitive to green, but less sensitive to blue and red. Chemists led by Hubert Huppertz have now developed a new red phosphor whose light is well perceived by the eye. This increases the light yield of white LEDs by around one sixth, which can significantly improve the energy efficiency of lighting systems.



The crystal structure of the SALON phosphor is the reason for its excellent luminescence properties (Credit: Uni Innsbruck)

Light emitting diodes or LEDs are only able to produce light of a certain color. However, white light can be created using different color mixing processes. "In a white LED, red and yellow-green phosphors are excited by the light from a blue diode. The particles emit light in the red and green range, and in combination with the blue light they produce white light," describes Hubert Huppertz from the Department of General, Inorganic and Theoretical Chemistry at the University of Innsbruck, Austria. He and his team are working on improving the red and green phosphors. In cooperation with OSRAM Opto Semiconductors, his team has now succeeded in synthesizing a new red phosphor that has excellent luminescence properties and can make LED lighting significantly more energy-efficient.

Color shift improves luminous efficacy
The powerful red phosphor $Sr[Li_2Al_2O_2N_2]:Eu^{2+}$, named SALON by the researchers, meets all the requirements for the optical properties of a phosphor. The development goes back to research carried out by Hubert Huppertz at the University of Bayreuth. As part of his doctoral thesis, he developed nitrides doped with europium that are fluorescent. These were then further optimized by the working group in Munich and are now widely used. These red phosphors are partly responsible for the fact that LEDs no longer only glow cold white, but also warm white. Interestingly, the human eye reacts most sensitively to the color green. In the blue and red areas, the eye is less sensitive. Although these phosphors emit red light in the visible range, a large part of the energy goes into the infrared range, which the human eye does not perceive. The fluorescent material developed in Innsbruck has now succeeded in slightly shifting the light emission from red towards blue.

"Since initially only a few very small particles were available in a very inhomogeneous sample, it was difficult to optimize the synthesis," said doctoral student Gregor Hoerder. The breakthrough came when the researchers were able to isolate a single-crystal from one of the most promising synthesis products and thus determine the structure of the new material. "The substance is synthesized in such a way that it emits more orange than red," says Hubert Huppertz. "SALON has less energy loss as it emits exactly in the red range we can see."

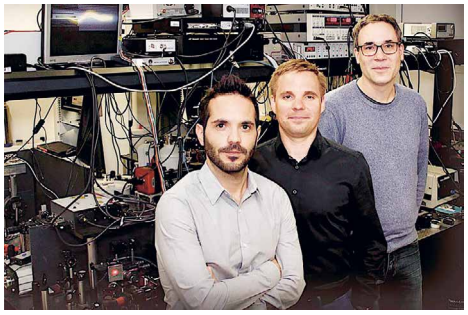
Acknowledgements:
OSRAM Opto Semiconductors, a strong industrial partner, the Fraunhofer Institute for Microstructures of Materials and Systems IMWS in Halle and Dirk Johrendt's research group at the Ludwig Maximilian University in Munich were also involved in further characterizing the new material.
The development has already been registered for patent. ■

References:
The original paper has been published under the title $Sr[Li_2Al_2O_2N_2]:Eu^{2}+$ - A high performance red phosphor to brighten the future" at https://www.nature.com/articles/s41467-019-09632-w

Publishing researchers:
Gregor J. Hoerder, Markus Seibald, Dominik Baumann, Thorsten Schröder, Simon Peschke, Philipp C. Schmid, Tobias Tyborski, Philipp Pust, Ion Stoll, Michael Bergler, Christian Patzig, Stephan Reißaus, Michael Krause, Lutz Berthold, Thomas Höche, Dirk Johrendt & Hubert Huppertz

TU Vienna - New Method to Generate Light from Exotic Particle States

A new type of light-emitting diode has been developed at TU Wien. Light is produced from the radiative decay of exciton complexes in layers of just a few atoms thickness.



The research team that succeeded in generating light by using a so-called "multi-particle exciton complexes": Aday Molina Mendoza, Matthias Paur, Thomas Müller (left to right)

When particles bond in free space, they normally create atoms or molecules. However, much more exotic bonding states can be produced inside solid objects.

Researchers at TU Wien have now managed to utilize this: so-called "multi-particle exciton complexes" have been produced by applying electrical pulses to extremely thin layers of material made from tungsten and selenium or sulfur. These exciton clusters are bonding states made up of electrons and "holes" in the material and can be converted into light. The result is an innovative form of LED in

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- Horticulture

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LUMILEDS

which the wavelength of the desired light can be controlled with high precision. These findings have now been published in the journal "Nature Communications".

Electrons and holes:
In a semiconductor material, electrical charge can be transported in two different ways. On the one hand, electrons can move straight through the material from atom to atom in which case they take negative charge with them. On the other hand, if an electron is missing somewhere in the semiconductor that point will be positively charged and referred to as a "hole". If an electron moves up from a neighboring atom and fills the hole, it in turn leaves a hole in its previous position. That way, holes can move through the material in a similar manner to electrons but in the opposite direction.

"Under certain circumstances, holes and electrons can bond to each other", says Prof. Thomas Mueller from the Photonics Institute (Faculty of Electrical Engineering and Information Technology) at TU Wien. "Similar to how an electron orbits the positively charged atomic nucleus in a hydrogen atom, an electron can orbit the positively charged hole in a solid object."

Even more complex bonding states are possible: so-called trions, biexcitons or quintons which involve three, four or five bonding partners. "For example, the biexciton is the exciton equivalent of the hydrogen molecule H_2", explains Thomas Mueller.

Two-dimensional layers:
In most solids, such bonding states are only possible at extremely low temperatures. However the situation is different with so-called "two-dimensional materials", which consist only of atom-thin layers. The team at TU Wien, whose members also included Matthias Paur and Aday Molina-Mendoza, has created a cleverly designed sandwich structure in which a thin layer of tungsten diselenide or tungsten disulphide is locked in between two boron nitride layers. An electrical charge can be applied to this ultra-thin layer system with the help of graphene electrodes.

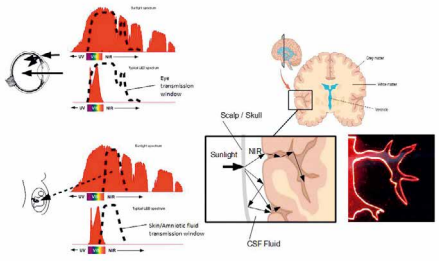
"The excitons have a much higher bonding energy in two-dimensional layered systems than in conventional solids and are therefore considerably more stable. Simple bonding states consisting of electrons and holes can be demonstrated even at room temperature. Large, exciton complexes can be detected at low temperatures", reports Thomas Mueller. Different excitons complexes can be produced depending on how the system is supplied with electrical energy using short voltage pulses. When these complexes decay, they release energy in the form of light which is how the newly developed layer system works as a light-emitting diode.

"Our luminous layer system not only represents a great opportunity to study excitons, but is also an innovative light source", says Matthias Paur, lead author of the study. "We therefore now have a light-emitting diode whose wavelength can be specifically influenced - and very easily too, simply via changing the shape of the electrical pulse applied." ■

About the Photonics Institute:
The Photonics Institute focuses its research on the generation of ultrashort high intensity laser pulses, generation of THz pulses and realization of nano-photonic devices as well as their applications. The Photonics Institute is also teaching the full spectrum of photonics in the TU Wien Bachelor and Master programs.

3D Bio-Optical Models Reveals How the Human Body Uses the Entire Solar Spectrum

History teaches that global changes to the public's environment mandate a higher level of scrutiny to ensure that we first do no harm. In "Melatonin and the Optics of the Human Body" published in the journal, Melatonin Research, Zimmerman and Reiter combine optical ray tracing from lighting and ESR data from the medical industry to model the 3D free radical distributions generated by lighting sources in the human body.



NIR light reaches deeper regions of the body. The image shows examples from different body regions

The article suggests how the interaction between melatonin and sunlight may play a much broader role in our health than existing circadian theory suggests. The 3D bio-optical models show that Near Infrared (NIR) uniquely interacts with the majority of adult cells and up to 100% of the cells in the fetus and young children. The work supports the premise that the body assumes that we are exposed to predominately NIR emitters (Sun) and that the body uses NIR to protect us from the damaging effects of UV. The absence of NIR in visible only emitters (LED, OLED, CFL) may lead to higher oxidative stress and may provide a direct link to diseases that are on the rise in modern society.

The optics of the eye, womb, skin, and brain are shown to collect and localize NIR in some of our most sensitive tissues. The recent realization that mitochondria produces melatonin in virtually all cells in quantities that are orders of magnitude greater than the amount produced in the pineal gland supports instead the existence of a subcellular melatonin reservoir stimulated in part by NIR.

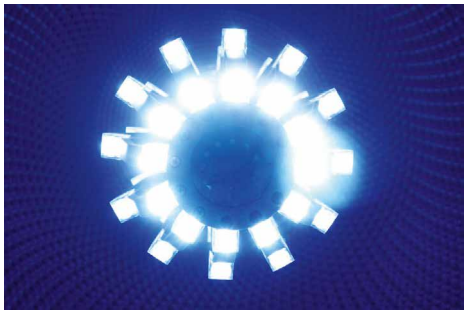
Ironically for the last 60 years, the public has been exposed to therapeutic levels of NIR by incandescent bulbs in their homes mediating the possible negative impact of fluorescents and supporting better sleep. This is no longer the case. The elimination of NIR from modern society is occurring not only because of visible only LED lighting, but also via low E glass (blocks NIR) and concerns over skin cancer reducing time in natural sunlight. In a sense a perfect storm has been created.

Based on this work, a review of the literature, and the lack of research into the biological impact of visible only emitters, the article suggests that it is time for the lighting and medical community to work together. ■

Free access to the article is available with registration at: http://melatonin-research.net/index.php/MR/article/view/19

CIE Publishes Position Statement on the Blue Light Hazard

CIE announced that CIE has published a Position Statement on the Blue Light Hazard which is approved by the CIE Board of Administration, which includes the Directors of all the CIE Divisions.



Blue light hazard is a controversial topic and the position taken by CIE in their statement provides guidance and references

CIE position statements are always approved by the CIE Board of Administration, which includes the Directors of all the CIE Divisions (the bodies that carry out the scientific work of the CIE), after first ensuring agreement with the relevant CIE Technical Committees.

This position statement puts into context the use of the term "blue light hazard" in line with the CIE's current position on this term. It provides reassurance that people are normally not at risk of exceeding the internationally agreed blue light hazard exposure limits from white light sources used for illumination. However, it does warn about the inappropriate use of blue LEDs in products, such as toys, which are primarily used by young children.

The position statement is written in English, and is freely downloadable from the CIE website. Also available for download are various translations of the position statement. ■

IoT Ready Alliance Dissolves in the NEW Zhaga Consortium

Zhaga and the IoT Ready Alliance are pleased to announce that they have agreed to align their efforts and to proceed as a single organization under the Zhaga Consortium. The objective is to foster a harmonized, global set of interface specifications for sensor-to-luminaire integration and to remove confusion in the industry.

The NEW Zhaga's widened scope to address new growth areas motivated the IoT Ready Alliance to dissolve with the intent that its members join Zhaga

In summer 2018, the Zhaga Consortium and the IoT Ready Alliance entered into a dialogue to explore the possibility of aligning their standardization activities for sensor-to-luminaire integration. At the beginning of 2019 the organizations agreed that it was best to harmonize their efforts with the objective of easing the adoption of a singular set of interface specifications and of removing any confusion in the Industry.
As IoT Ready Alliance President Neeraj Purandare points out: "The best way forward was to capitalize on the breadth of the NEW Zhaga, to encourage them to carry the standard forward, and to dissolve the IoT Ready Alliance with the intent that its members join Zhaga."

Background to this decision was the fact that the NEW Zhaga went live in December 2018 with a widened scope of work to address new growth areas in IoT and the service economy. The NEW Zhaga focuses on interoperability and executes a.o. a strong program to address interfaces for smart components, such as sensors and communication modules.

"Zhaga invites all members of the IoT Ready Alliance to sign up for Zhaga membership and to participate in our working groups," says Dee Denteneer, Secretary General of the Zhaga Consortium. "The harmonization will bring a clearer and stronger voice to the market and will fuel the adoption of smart lighting innovation, especially in the US market."

Zhaga has experienced a strong interest in their latest specification, the Book 18, defining interoperability between outdoor luminaire and smart sensing / communication nodes. Another specification which is close to approval is Book 20 about a smart interface for indoor luminaires and sensing/ communication modules. ■

DiiA Announces DALI Summit 2019 - Sept. 25th in Bregenz

The Digital Illumination Interface Alliance (DiiA) has announced that it will hold its first DALI Summit in Bregenz, Austria, on September 25th, 2019.

DiiA will hold the first DALI Summit co-located with LpS & TiL 2019 in Bregenz (AT) where Scott Wade held a lecture in 2018

The DALI Summit 2019 will cover the capabilities and features of DALI; the changes to be found in DALI-2; applications and case studies, including practical information for specifiers and installers; the new DiiA specifications on intra-luminaire DALI; how DALI fits in the wider world of connected lighting and IoT; and last but not least the joint certification program with Zhaga.

The DALI Summit 2019 will also include a Panel Debate with leading experts, as well as a showcase of DALI products, solutions and services on the exhibition floor.

The DALI Summit 2019 will be co-hosted with the 9th LpS and the 3rd TiL, to take place from September 24th to 26th in the Opera House Bregenz.

Experts who are interested in holding a talk at the DALI Summit 2019 may contact DiiA directly or submit their abstract through the LpS/TiL websites under the Call for Papers/Speakers.

The event is a collaboration between DiiA and Luger Research e.U., the organizer of the LpS/TiL events.

"DiiA is very pleased to launch the DALI Summit to run alongside the highly regarded LpS and TiL events," said Arnulf Rupp, Chair of the Board of Directors of DiiA. "Our speakers will offer a wealth of information on DALI lighting control, with a focus on the importance of the DALI-2 certification program." ■

TECHNICAL REGULATORY COMPLIANCE UPDATE

Segment	Product	Standard (Certification)	Region	Technical Regulatory Compliance Information
Safety Standards	Lighting Products	IS 10322	India	The Bureau of Indian Standards (BIS) introduces a new guide for implementation of an extension to the existing IS 10322 (Part 5/Sec 5) Particular requirements of floodlights within the luminaire standardization. Beside other significant modifications photometric requirements for LED luminaires are added in this amendment 1 to the standard. Further more new applications without complying with the amendment 1 are only accepted up to one month before the last date of implementation. The guidelines and the amendment will come into force on September 18, 2019.
Energy Efficiency	Self-Ballasted LED Lamps	Ministry Notice	Taiwan	New energy performance standards and methods regarding the inspection of self-ballasted LED lamps were published in Taiwan. The Ministry of Economic Affaires presented a Notice which issued a new minimum energy performance standard on 21 March 2019. Lamps which are addressed in this standard are the products within the scope of CNS 15630 and others designated by BSMI. It excludes LED lamps where the rated and actual CRI is above 95. According to this standard all LED lamps should be tested. The notice will come into force on January 2021.
Safety Standards	Double-Capped LED Lamps	Resolution No.: 21365	Chile	New requirements for the approval of double-capped LED Lamps were introduced by the Chilean Ministry of Energy which adopted the Resolution No.: 21365 from 28 November 2017. This Resolution approves the safety protocol PE No.: 5/25 which addresses double-capped LED lamps that are intended to replace G5 or G13 linear fluorescent lamps. It is only meant for such luminaires where the internal wiring has not to be adopted for the replacement. The protocol does not cover the situation where luminaires need to be re-wired internally. From March 30, 2019 all relevant products must have a certificate according to the above mentioned Resolution. It is important, that this certificate is given by an accredited certification body and has to be authorized by the Superintendence of Electricity and Fuel (SEC) The european standards which are referenced regarding the certification procedure are the IEC 62776:2014 and the UNE-EN 62776:2015.
Energy Efficiency	Directional Lamps	Resolution No.: 264, 2019	Ukraine	The Ukrainian Cabinet of Ministers gave its approval to Resolution No. 264 on 27 March 2019. This resolution covers the eco-design requirements for directional lamps, LED lamps and related equipment. The regulation is based on or similar to the EU Regulation (EC) 1194/2012. Included products are directional radiation lamps, LED lamps and equipment designed for installation between the mains and lamps, including control gears and control devices, also when the mentioned products are integrated into other products. Also the requirements for the product information for special purpose products are covered by this technical resolution. LED modules that are included in luminaires (fixtures) with a quantity of less than 200 units per year are excluded from this resolution. It does not apply to LED modules sold as part of fixtures that are put into circulation in quantities of less than 200 units per year. This resolution will come into force on 4 October 2019.
Energy Efficiency	Lighting Products	Cabinet Order No.: 267; Cabinet Order No.: 144	Japan	Japan's Cabinet created an amendment to the Enforcement Ordinance of Rational Use of Energy Act on 3 April 2019. This amendment extends the target of the current regulations on specific energy consumption devices. Instead of addressing luminaires using only fluorescent lamps as main light source luminaires (as a whole) are meant and bulbs (as a whole) instead of speaking only about LED lamp bulbs or incandescent bulbs and so forth. (Article 18) This enforcement ordinance came into force on 15 April 2019.
Safety Standards	Self-Ballasted LED Lamps	EN 62560:2012/ A11:2019	Europe	The amendment added new requirements concerning the fixing of conductors to prevent reduction of clearance and creepage distances within a selfballasted LED-lamp. The DOW is 2021-12-26.
Energy Efficiency	Lighting Products	Single lighting regulation (Ecodesign require-ments)	Europe	In the actual draft regarding ecodesign requirements of light sources the european commission includes all light sources and technologies in one single regulation. The existing regulations (EC) 244/2009, (EC) 245/2009 and (EU) 1194/2012 are planned to be repealed on 1 September 2021. From this date the new regulation should come into force. The efficiency requirements will be tightened as well as the networked standby requirements. New requirements will be added for the light quality like stroboscopic effects and flicker for LED and OLED light sources, and efficiency requirements for separate control gear.
Energy Efficiency	Lighting Products	Single lighting regulation (Labelling)	Europe	On 11 March 2019 the European Commission issued the actual draft of the Regulation (EU) 2017/1369 establishing a framework for adopting regulations on EU-wide energy labelling of energy-related products. This regulation will cover light sources in general even when they are parts of "containing products" like furniture or household products with integrated light sources. It covers all lighting technologies. A new layout of the energy label will contain a QR code to find light source data in the EU Product Database. More detailed information will be required to be entered into the Product Database visible to consumer but also to market surveillance. It is planned to have this regulation come into force on 1 September 2021, repealing the Regulation (EU) 874/2012. The present obligation of energy labeling of luminaires will be dropped shortly after publication of the new regulation.

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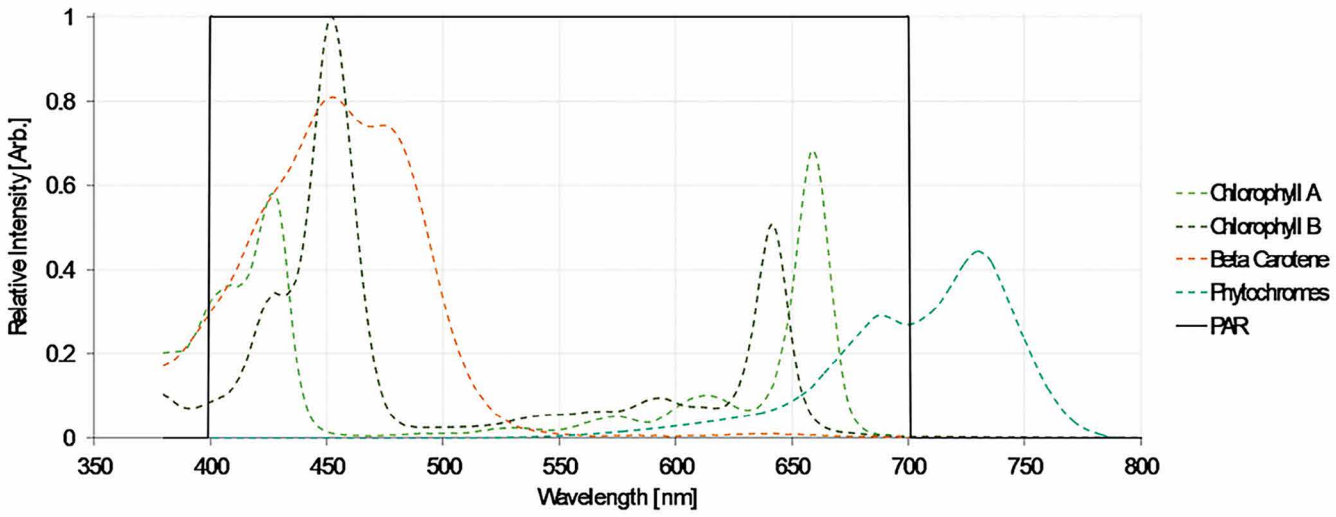
Horticultural Lighting - The Root to International Standards

Plants have evolved to make the most of the conditions in which they naturally grow. For some plants, this environment will be fully supportive; it may be less so for others. In general, the plant with the fully supportive conditions will predominate in the absence of external intervention. Humans have changed plants over the centuries, selectively growing the plants that provide maximum perceived benefits in terms of color, smell, yield and, perhaps more recently, nutritional value. For most of our evolution, we have had to make use of the environmental conditions available. The desire for cheap food, all year around, and attempts to minimize "food miles" has increased the move towards providing totally constructed growing environments.

Division 6 of the International Commission on Illumination (CIE) is responsible for photobiology and photochemistry. Most of the Division's work has concentrated on the effects of optical radiation (this being radiation from the ultraviolet through to the infrared) on people. However, the CIE has been encouraging international work on the impact of optical radiation on plants and specifically for horticulture since at least the 1980s. CIE Technical Committee (TC) 6-42 covered "Lighting Aspects for Plant Growth in Controlled Environments" and TC 6-61 "Measurement of Radiation Using the Phytometric System for Plant Applications". Considerable development work was carried out by these TCs, but the decision was taken to defer their activities in 2015, pending discussions with other organisations.



Providing sufficient nutrition for the rapidly increasing population on earth belongs to the most crucial tasks of the 21st century. Improved horticulture methods and technologies are recognized as a key element. Horticulture lighting has therefore become an increasingly important topic. Sound knowledge on the requirements are crucial and knowing how to use the action spectra of photosynthetic active pigments instead of the V(λ) spectral luminous efficiency function is inevitable

The CIE International Lighting Vocabulary [1] already includes terms for some aspects of horticultural lighting and these are used by a number of national voluntary standards, such as those published by the American Society of Agricultural and Biological Engineers (ASABE) [2].

A lot of effort has been put into understanding the complexities of growing plants under electric lighting. Kniep and Minder [3] are generally credited with the first attempts at defining an action spectrum for the absorbance and quantum yield for plants. Hoover [4]and then McCree [5] built on this early work. From a scientific perspective, this certainly seems to be an ideal starting point, particularly as one of the fundamental laws of photochemistry is that a photon of optical radiation has to be absorbed before a photochemical reaction can occur. What McCree discovered is that the action spectrum varied between plant species, indeed also between plants grown outdoors and those grown indoors, but that there was a general envelope of response over the wavelength range 350 nm to 750 nm.

Of course, the optimum growing conditions for plants depend on many more factors than the spectral composition of the light and there may be some synergy between these other factors and specific wavelengths of exposure. It is also likely that the response of the plant may be dependent on multiple wavelengths from different parts of the optical spectrum, either working together or against each other. Therefore, it may be important to consider the effects of not including some wavelengths, as well as ensuring that the key wavelengths are included.

The dosimetry required to assess the exposure of plants is complex in practice. The key part of the work of CIE TC 6-61 had been an attempt to address this. During stages of growth, during the season and even during the day, the spectral power distribution of optical radiation falling on a given leaf will vary. As plants grow, they will tend to influence the spectral power distribution received by neighbouring plants and indeed by their own leaves. This will be true for plants growing naturally outdoors, for those growing in greenhouses under sunlight and those grown completely under electric lighting.

Clearly, plants respond differently to light than people, which means that familiar quantities such as the lumen, based on the V(λ) spectral luminous efficiency function, are not useful to horticulture. The American Society of Agricultural and Biological Engineers, in ANSI/ASABE S6402, has suggested that a single action spectrum is not appropriate because it is highly variable between plant species. Therefore, it recommends that photosynthetically active radiation (from 400-700 nm) should not be weighted for most horticultural quantities. This effectively means they are recommending an action spectrum with a weighting of one from 400 nm to 700 nm and zero outside those wavelengths.

In addition to growth, different wavelengths of optical radiation are responsible for particular aspects of a plant's development, including the development of any required flowers and fruit. LEDs have provided the opportunity to vary the light spectrum throughout the stages of a plant's life, taking into account the varying spectral needs, length of time of light exposure in a given day and the number of photons incident on the plant. However, the science is still maturing and there is an element of "try it and see". In time, it may be possible to standardise a series of action spectra to assist manufacturers of LED products and growers with optimising the light exposure conditions.

The CIE is a technical, scientific and cultural non-profit organization whose first objectives is: to provide an international forum for the discussion of all matters relating to the science, technology and art in the fields of light and lighting and for the interchange of information in these fields between countries. Until recently, most of the work of the CIE has focused on lighting for people, but of late, the CIE has initiated discussions with a number of professional and trade bodies involved with horticultural lighting. An outcome of these discussions is a workshop on Horticultural Lighting, which will be held as part of the conference programme of the CIE's 29th Quadrennial Session in Washington DC in June 2019. Various aspects of what is known and what is not known about providing evidence-based horticultural lighting will be discussed [6].

Another matter to consider in conjunction with horticultural lightning is the need of people who work in areas that are set up primarily for horticultural benefits and the impact of the lit environment on those people. National legislation is likely to restrict exposures to levels below exposure limit values. However, consideration also needs to be given to any impact on both the ability to undertake visual tasks and any non-visual effects of the lighting on the workers.

Starting from this basis of the CIE's scope and activities, and the CIE's standing as an international standardization body recognised by ISO, now is the time for the CIE to bring to fruition standards, reports and other publications concerned with horticultural lighting - starting with the roots (the basic science). ■

Note:
Anyone interested in supporting this work as an organization or as an individual, can contact the CIE by sending an email to ciecb@cie.co.at.

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Zhaga-D4i Certification Signals Plug-and-Play Interoperability

The new Zhaga-D4i certification program and logo indicates plug-and-play interoperability of luminaires, sensors and communication nodes, and represents an important collaboration between two major, innovative lighting-industry organizations, Zhaga and DiiA.

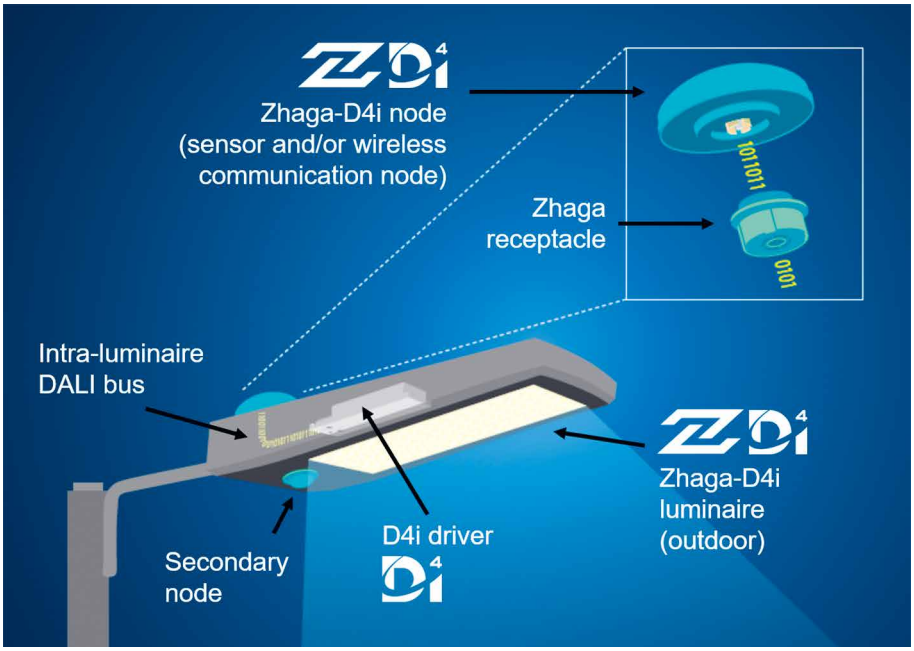
As open, global lighting industry associations involved in standardization, the Zhaga Consortium and the Digital Illumination Interface Alliance (DiiA) bring together several hundred member companies from across the lighting industry. The new Zhaga-D4i certification program is the result of an ongoing cooperation and consensus between the two organizations, and combines expertise in different areas to achieve a goal that brings substantial benefits to the lighting market.

In technical terms, Zhaga and DiiA have standardized the interface between outdoor LED luminaires and sensors and/or communication nodes. The initial focus is on outdoor lighting, with indoor applications being a work in progress.

The standardization effort brings together complementary specifications from the two organizations, which cover mechanical fit, digital communication and power requirements. This ensures plug-and-play interoperability of the luminaires and nodes, backed by the Zhaga-D4i certification program.

Zhaga-D4i certification allows qualifying luminaires and nodes to carry the dual Zhaga and D4i logos, as shown in the image. This provides a clear indication of plug-and-play interoperability, which is a strong benefit for specifiers, purchasers, installers and end users.

The certification logos are trademarked to prevent misuse, and provide an established brand for product marketing. Certified luminaires and components are available from multiple suppliers, establishing an ecosystem of compatible products. Zhaga-D4i certification ensures that luminaires are future-proof, and will be able to host next-generation Zhaga-D4i nodes.



The important collaboration between two major, innovative lighting-industry organizations, Zhaga and DiiA, led to the new Zhaga-D4i certification program. The new logo indicates plug-and-play interoperability of luminaires, sensors and communication nodes

Market Drivers

The cooperation between Zhaga and DiiA is driven by market requirements for smart, interoperable LED luminaires with pluggable IoT connectivity.

A plug-and-play, socket-based connectivity system makes it easy to add or upgrade sensors and/or communication nodes, which in turn enables luminaires to keep pace with rapid developments in digital networking and sensing technology. By replacing the node rather than the entire luminaire, the luminaire is future-proofed. Also, where the node allows wireless communication, this facilitates the connection of the luminaire to an external lighting-control network. Other functionalities beyond lighting can also be supported.

In addition, the use of intelligent DALI-2 drivers enables luminaires to collect, store and report a wide variety of data, in a standardized manner. A smart luminaire can communicate and interact with a lighting-control network, providing energy consumption data, or fault detection, or many other parameters. In turn, this can result in significant cost savings in terms of energy efficiency and maintenance.

Complementary Specifications

The already-published Zhaga Book 18 Edition 1.0 specification defines the mechanical fit and electrical pins for a connectivity system for outdoor LED luminaires. An extensive overview of this specification has been presented in a previous article [1]. The Zhaga connector allows sensors and/or communication nodes with a standardized Zhaga Book 18 plug to be easily connected to the corresponding receptacle (socket) in the luminaire.

The Zhaga connector makes it easy to add or change sensors and/or communication nodes, and to upgrade the luminaire during its lifecycle. However, for full plug-and-play interoperability, as well as enabling luminaire features such as intelligent interaction with external networks, the connectivity system also needs to take care of power and lighting-control requirements.

A solution is provided by the D4i specifications for intra-luminaire DALI, which have been published by DiiA. D4i represents a specific set of features associated with DALI-2 certification. The upcoming Edition 2.0 of Zhaga Book 18 references these D4i specifications. As the name suggests, intra-luminaire DALI refers to a DALI bus within an individual luminaire. The bus connects the LED drivers inside the luminaire with any DALI control devices, for example a sensor or an application controller. As well as providing power to the LEDs, a D4i driver has an integrated bus power supply that can drive the other DALI components.

In the Zhaga-D4i case, each receptacle on the luminaire is connected to the internal DALI bus. When a node is plugged into the receptacle, this establishes bi-directional interaction between the node and the D4i driver(s) using the well-established and standardized DALI-2 protocol.

The D4i specifications ensure that power is available to the luminaire's Zhaga receptacle. In addition to the integrated DALI bus power supply, each Zhaga-D4i certified luminaire also includes a 24V auxiliary power supply (which can be part of the driver or a separate component inside the luminaire).

Smart D4i Drivers

But the D4i specifications go further, by standardizing the storage and retrieval of data in the DALI memory banks of a D4i driver. The Part 251 specification describes how to store luminaire-specific information that has no impact on the functionality of the driver. For example, a manufacturer can encode data about the luminaire - such as part number, or nominal light output - in the factory. When the luminaire is installed, the data is readily available to the lighting-control network. A utility company or lighting-installation owner could use this capability to monitor and manage their lighting assets accurately and efficiently.

The Part 252 specification standardizes the storage and reporting of data relating to the driver's usage of energy and power. Meanwhile, Part 253 focuses on diagnostics and maintenance, and cove variety of data related to the light source and luminaire.

Certification Program

Later this year, Zhaga-D4i c be available for LED lumina powered Zhaga Book 18 re use D4i drivers inside. Likev possible to certify Zhaga-D sensors and/or communica a Zhaga Book 18 plug and

Zhaga-D4i certification for l granted after a Zhaga test c confirmed compliance with interoperability requirement 18. One of the key criteria is of power to the socket. Zha check that all drivers inside already D4i-certified. A cert luminaire will be eligible to c Zhaga and D4i logos, and v the public database on the

For a Zhaga-D4i node, the t the manufacturer to achieve as part of the DALI-2 certifi operated by DiiA. DALI-2 ce requires the manufacturer t results to the DiiA website; granted after the test result DALI-2 control device or dri successfully implemented a required by D4i, then the D4 permitted on the product. A products will be listed in the database. After D4i certifica with a Zhaga plug can be s Zhaga test centre, where Zh certification is confirmed.

Speakers from Zhaga and D progress updates on the Zh certification program at the Symposium and the DALI S (September 24-26 in Brege

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Tech-Talks BREGENZ - Julian Carey, Marketing Manager at SLD Laser

Julian Carey

Julian Carey is the Product and Technical Marketing Manager at SLD Laser, a leader in the commercialization of laser light sources for automotive and specialty lighting applications. At SoraaLaser, Julian oversees product strategy and marketing for new laser based light sources. In his prior role, Julian acted as head of marketing at Intematix, a leading innovator of phosphors and remote phosphor components for high-quality LED lighting. His previous roles were marketing and developing scanning laser based display systems at Prysm and LED based lighting components and systems at Philips, Lumileds and Agilent. He holds a BS degree in Mechanical Engineering from Stanford University and an MBA from MIT Sloan.

In 2016, Nobel Laureate, Professor Shuji Nakamura held a key note speech at LpS. As the founder of Soraa and SLD Laser, he named laser lighting as the next, innovative step and disruption in lighting. He emphasized the need to focus on light quality and the tailoring of LED lighting to the natural needs of humas, providing light that mimics sunlight as closely as possible. It was therefore self-evident that LED professional would invite Julian Carey, the Product and Technical Marketing Manager at SLD Laser, for a Tech-Talk when he was at the LpS 2018 in Bregenz. We asked him for an update on the status of laser lighting, business strategies and future prospects and how laser lighting has developed since Professor Nakamura's statements in 2016.

LED professional: Thank you for being here and agreeing to this interview. Can you tell us a little about SLD Laser?

Julian Carey: Yes, of course. SLD Laser is an independent spinout. Shuji Nakamura, our co-founder, who won the Nobel Prize in physics in 2014, and who also founded SORAA, wanted to move on towards laser technology. He saw that there was so much potential for blue laser to make a contribution in lighting. So as a result, several of the co-founders left SORAA, and founded SLD Laser.
Both companies now have their offices in Silicon Valley but they are independent companies that have independent customers. Markets, technology and products - pretty much everything is different at this point. SLD Laser got its start with automotive technology - going into the headlights and became an automotive supplier and the company is going into production this year with those applications.

That gave it a good foundation to go into general lighting, or specialty lighting really: Spots, entertainment, architectural lighting and some fiber optic applications.

The company is headquartered in Santa Barbara close to the University of California, where we have a lot of access to technology. They have a very strong department there, which specializes in high power semiconductors. It's an important location but most people now work for the SLD Laser in the Silicon Valley in Northern California.

LED professional: How many people work for SLD Laser?

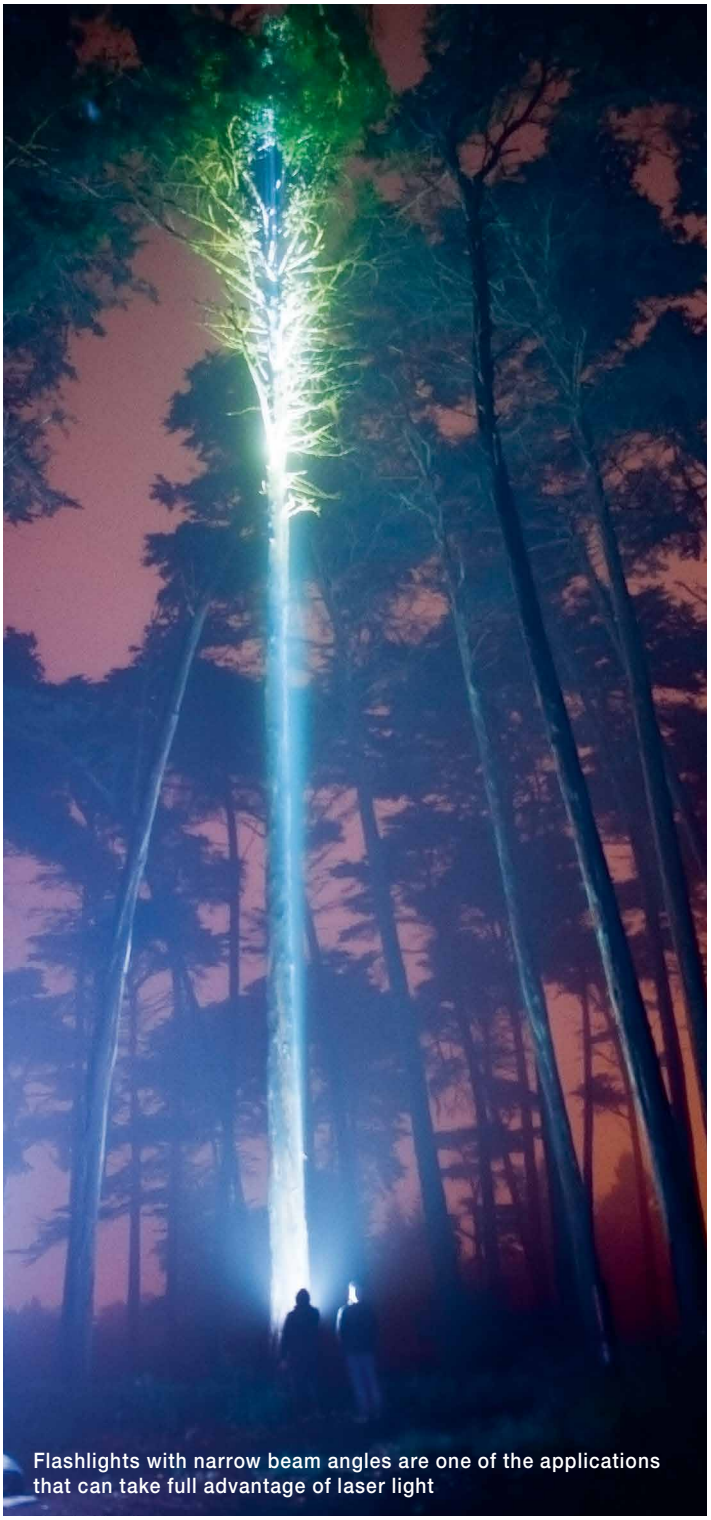
Julian Carey: Now we have 120 people worldwide, we're actually growing quite a bit. And that's really to ramp operations as we go into automotive headlight production, which started in October 2018. Before that we shipped quite a few verification units of our laser light SMD product. It is a LED-like square shaped SMD with 500 lumens. That went into production in September. So we are already shipping several thousand units.

LED professional: You said that SLD Laser is making all the automotive headlights, so are you doing the complete process from the solid-state laser with everything that is needed for electronics and the complete assembly?

Julian Carey: That's right.

LED professional: How is it split? Is the laser one part and the assembly another?

Julian Carey: It's sort of like the business model. In summary - we fabricate laser chips in a two-stage process. The epi fabrication is in Santa Barbara and the wafer fabrication is in Freemont. Once those chips are made - they are like the



Flashlights with narrow beam angles are one of the applications that can take full advantage of laser light

Extending the reach of a vehicle's high beam was one of the first mass laser lighting applications

equivalent of LED die - they're blue lasers. The difference is that the light density is about 100 times that of an LED. Then we make different modules. So right now we have two main product platforms. One is the fiber module for automotive headlights - where the laser module is separated from the phosphor by a fiber optic cable - and that has some advantages thermally and optically. And then the SMD product combines lasers and phosphor in one SMD package to make it present itself like an LED.
So you put it on the PCB and use the same type of optics.

Business models are a little bit different between the two. We fit into the automotive infrastructure in a very traditional way. We supply our light module to the headlamp sub-system manufacturer. And they, in turn, would supply the complete headlight module that then gets assembled into the vehicle by the car manufacturer. So SMD is more straightforward and traditional, like the LED model, where we engage with lighting-OEMs, who then manufacture lighting equipment.

LED professional: You just said that this SMD laser is about 500 lumens. But for a car headlight, you need a lot more - so how do you achieve that?

Julian Carey: Specifically about the automotive roadmap: right now we only do the high beam extender function which is about 400 lumens. So that gives you about a one-kilometer range of visibility - usually in combination with the high beam at very high speeds. The complete headlight module still has many LEDs for the low beam, the daytime running light and all of those indicators. The future will have lasers effectively implementing the entire headlight by combining laser chips. But the nice thing about the fiber module architecture is that you can combine multiple lasers into one fiber and then when they hit the phosphor you can have a very high illuminance source. Through the headlight, in its entirety, you'd probably need about 2,000 lumens and probably about five laser chips but you'd still maybe have a single phosphor, so you'd still have one source that you could then manipulate dynamically. There are a lot of ideas about how to combine different pieces of the entire headlight.

LED professional: Is there a technical limitation?

Julian Carey: The only limit is really the thermal limit of the phosphor. But for the phosphors used in automotive lighting, that's quite high. It's easily 200°C. We just make sure that we don't make it so intense that it would damage the phosphor. Nonetheless, we can stay within safe range of the phosphor but still, in the automotive context, have luminance levels that are six, seven or even eight times more dense than LEDs can. This gives you optical control and sharp cutoff and a whole lot of benefits like the ability to use the dynamic reflectors.

LED professional: So just to understand how the laser and the conversion work: There is a very, very narrow blue beam, and this beam hits the converter. What is the distribution of the white light behind the converter?

Julian Carey: There are a few stages to that. I think some people imagine laser chips as having a perfect beam right out of the facet, but they don't, actually. The light is still diverging. It comes from a very, very tiny spot but it's quickly diverging. In the fiber module case, there are optics that are right close to the laser that collimate the beam and then get it back - refocus - so that it can enter the fiber.
The fiber has a distal end that has its own diversions properties.
So when it is placed with the phosphor, it has to be placed very carefully so that you have the right density. We basically try to have the light come to the phosphor in a highly uniform way so you don't have any hotspots. But the white light that results is very similar to an LED, just much smaller. It's still a diffuse, Lambertian distribution, it has good color over angle.
The systems just get a little more sensitive because positioning accuracy now becomes more important with a very high

Search lights and safety equipment for offroad vehicles is another strength of laser lights

luminance small source. Both with the SMD and the fiber module, the entire luminous area is only 300 micron in diameter for 500 lumens. It's just incredibly tiny and positional accuracy can sometimes be 100 micron, so you have to make sure that your optics are very, very precise.

LED professional: So the luminance area is about ten times smaller than that of an LED.

Julian Carey: That's right. But there are a lot of different kinds of LEDs. We compare with LEDs that are engineered for high luminance. Chip on Board arrays are actually very large sources, but if you look at automotive LEDs or LEDs specifically for very high intensity application, that's where that comparison is valid.

LED professional: So the big advantage of the LED laser is the small size.

Julian Carey: Exactly, because then you have design possibilities for very long throw and very small optics and very high efficiency through a collimated type of scenario. That's why all of our applications are basically spots or fiber optic. It's not really an application that is going to go into highly diffused or extended sources.

LED professional: There are many technical differences between the LED and the laser - starting with the manufacturing process of the die, going on to the accuracy of the assembly, and also the driver. One thing you mentioned was the high power LEDs and the fact that if you even have a little spec of dirt on the lens, it could be critical. How do you avoid something like that?

Julian Carey: We definitely have to make sure that the optics are high temperature capable. If you have plastic objects they could melt if their temperature capability is too low. You're absolutely right - anything has to have very clean surfaces throughout. Dirt particles on the optics will start absorbing energy. That is very relevant for these types of sources. So the laser module itself has to be done very precisely, with no obstructions. But even for the white light part, it's still pretty high density. But at the end of the day, we have guidelines for optics design and how to handle the source and so far it seems to be working okay. In most of these applications - especially in automotive - we end up in a sealed unit. The whole headlight module is very well sealed so there's really no contamination.

LED professional: How do you think this will end up in the future? Will you manufacture the module or would it be possible to hand over the technology, the lasers and phosphors and then tell the buyers to design the module themselves.

Julian Carey: We're pretty clear on our strategy largely because of Dr. Nakamura's vision of lighting. We are dedicated as a lighting component manufacturer. Will we end up doing some pure laser applications? I believe so, just because the technology is so strong and so interesting for bio-medical or sensing or material processing, 3D printing - whatever! Those things will be part of our business but the company focus and its identity is regarding lighting. All specialty lighting, including automotive, is always going to be very important for us. We may integrate even further up through the chain with the inclusion of more optics from the standpoint of electronic beam control. Dynamic beam, basically, for various applications. The nice thing is that those technologies are very complimentary with laser. The whole system works better when you have a very tight beam. We definitely don't expect to become a licensing company or anything like that. We want to fill our fabrication facility and make lots of lasers and modules.

LED professional: So your understanding of the module is the laser LED and conversion. Does it also include optics?

Julian Carey: No, we don't really include any optics. When the module goes to a company, like BMW, they do their own optics. We have recommendations for

Julian Carey speaks frankly about the topics that concern laser lighting technologies

partners, suppliers and design approaches. The nice thing about LEDs coming before us is a lot of the infrastructure and capabilities have already been put in place. That's why we work so hard trying to fit our technology into the standards. For example, we just got UL certification on the SMD device - which is the UL-8750 LED standard for how you handle it electrically, how you do different things optically and safety and all that kind of stuff. We are also certified for various automotive, IEC and IATF, standards. Basically, we just want to make a product that looks like what the market is already accustomed to, but works particularly well for certain applications like spotlights and high intensity.

LED professional: How big is the module and what is the wattage?

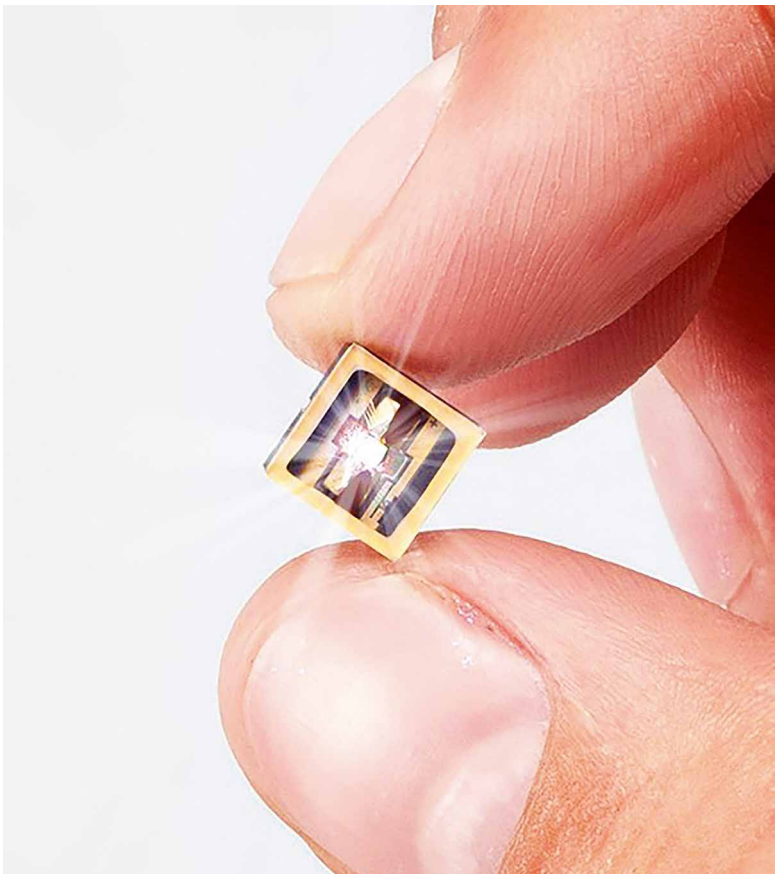
Julian Carey: The fiber module has two pieces connected with a fiber optic cable - which I believe is about 30 cm. Both elements are about the same size, so the laser module is about one cubic centimeter. The phosphor head is a flat piece that is about 2x1 cm. A lot of that robustness is for things like heat sinking in the automotive application. The SMD is 7x7 mm, so it really is an LED sized device. It's very, very compact. And each of those devices is about 400-500 lm and consumes about 12 watts. Lumen per watt is still less than LEDs but we expect to climb rapidly in efficiency over the years and become comparable.

LED professional: So that's twelve watts in one cubic centimeter.

Julian Carey: Yes, exactly. But these are all metal body parts so heat sinking and thermal management is a really important point. Our efficiency is always about light placement at distance - so basically the capability to put lux at a faraway point. Not total lumens per watt or things like that where, obviously, LEDs excel to a huge degree, today. But when you combine those two things, there can be interesting future applications, too. One difference is that LEDs have droop - with the increasing current they lose their efficiency - lasers don't have that drawback, so as we keep making better and better laser chips, we can keep going to higher and higher powers on a single platform, which has economic benefits.

LED professional: Shuji Nakamura's approach was building GAN on GAN. Is it the same with laser? Theoretically, you would have the same opportunities.

Laser fiber modules are currently the most powerful laser lighting solutions



SMD lasers are the latest development and while less efficient than LEDs in respect to lm/W in their application, it is a huge improvement with good prospects

Julian Carey: Yes, we are a GAN on GAN platform. We even use some of the equipment that was basically built for SORAA LEDs. In the wafer processing and build up from epi to wafer fab, some of the earlier steps are similar or almost identical. So we have the same kind of economy to scale potential there, if not more so because our chips are smaller. Architecturally, once you go to the final part of the fab, things diverge quite a bit. SORAA is doing a top-emitting chip. They're also doing 405 nanometer as emission spectrum. SLD has been once again standardized to 450 nanometers, driving conventional phosphors. Everything is the same, just a higher intensity level. Also, laser chips are side emitters so they're treated a little bit differently.

LED professional: Keeping in mind what future developments will be, where do you see the laser in the next couple of years?

Julian Carey: We are a complementary technology to solid-state lighting. There aren't really any ways that LEDs can do some of the applications that we do, particularly with injection into fiber optic cable, for example, or very tiny cable transports or very tiny optics or extremely long throw distances like one thousand meters for a high beam. Those are things that lasers are clearly excelling at. Surly projection displays is an own whole application itself. LEDs want to become more intense but they're reaching their limits when it comes to efficiency, capabilities, materials and the droop problem. So there's only one or two percent a year that they can advance, where we are still increasing all of our parameters fifteen to twenty percent per year.

So how do we see laser technology developing: It's going to be more products, higher lumen capability per module, to do more jobs. Four or five hundred lumen sources are nice for various applications but all of a sudden we see some of our customers combining six, ten, twelve units because a lot of lighting applications need more light. You may think about search and rescue, or entertainment lighting or stage lighting. 1000 lumen is sort of where things start for a source to be really useful and then it goes up quickly to 5000 or more. That's where we want to develop our source. We don't necessarily need to go to higher luminance - although the advantage there is still very large - but we'd just like to give more lumens per module. We also want to develop into architectural lighting. But we're still at 6000 Kelvin as a CCT. So we need to have a major thrust in order to develop a warmer CCT, at least to the sweet spot of commercial lighting at 4000 Kelvin. That's going to take another year, at least.

LED professional: What's the challenge to go to warmer color temperatures?

Julian Carey: One limitation is that the red phosphors are not as robust as the YAG yellow ones. So how do we combine them in the high

temperature materials that bind phosphors together? We aren't using silicone things, they would burn really fast. So it all has to be ceramic based for these intensities. Red phosphors don't lend themselves well to that and it's not clear how to combine them. We are working very hard on getting them integrated. At least you don't need too much red or too much other warm colors to bring the net to 4000 K, I believe. 2700 K is going to be a huge challenge, but I think for commercial lighting we'll be able to get there.

LED professional: That also means that currently, you can't go into areas where a high CRI is important. The advantage there is still on the side of the LED and if I understand it correctly, this probably won't change over the next few years.

Julian Carey: It's one of the challenges that we have. We have a clear mission ahead of us, in that regard because that's a major challenge. I think "outdoor" is looking very good but to get "indoor", like museum spots, or even just commercial track lighting, it would be nice to have warm color temperature track lighting with liquid crystal lens technology to modify the beam pattern. That would be a great complimentary system - but we would need to warm up the beam and get the CRI at least to a commercial lighting standard.

LED professional: That sounds like a lot of R&D work. Do you do all of your own R&D or do you network?

Julian Carey: All of our R&D is homegrown. It's Dr. Nakamura and his team that he's developed.

LED professional: But he is also at the university. Are they also involved in the research?

Julian Carey: It's really all on SLD laser. The only partnership I would call an R&D support partnership is the University of California. We're even developing our own phosphor approach using raw materials. At least at the module level we have the expertise and experience to develop those aspects. But we partner with optics makers and thermal management companies and electronics to make the rest of the system.

LED professional: We know that people are a little afraid of laser when it comes to safety. And with good reason when you think about increasing the power - so are there special safety technologies? Are you certified as in regards to the safety standards?

Julian Carey: One of the reasons we have UL certification for 8750 is that we have several failsafe aspects to our designs. For the fiber module, the first and foremost is that, if, for example, you disconnected the metal phosphor head, you would now have a bare fiber. However, we have a photo diode detector in the module to detect the failsafe. And then you know that something has been damaged or somebody is actually tampering with the system to make it into a laser. With the SMD, it's more of a case of what happens if, for some reason, there is no phosphor? That's where we have absorbing surfaces and beam blocks. The laser is actually facing inwards and would no longer be able to generate a laser beam exiting the part. And tampering with the SMD would basically destroy the part. You can have these failsafe systems for reflective phosphor architecture whereas most LEDs are a transmission architecture. So if you took a knife and you took off the phosphor, and then you have blue light - that's not the case with our devices. We always have the light directed inwards and it works pretty well.

LED professional: Another question I forgot to ask earlier: I've heard that the driver for a laser is simpler to design than a driver for an LED - is that true?

Julian Carey: It can be in some ways. One of the nice features of the laser is that we see very linear behavior. Once you drive above a threshold, you have a near perfect relationship between current and light output. The only major difference to LEDs is that lasers have a threshold current, so they don't actually begin amplification until current reaches a certain threshold. So up to the threshold you basically have a regime where the device is not really producing light, but drawing current. In your PWM architectures, you want to stay on the linear portion because you can't really dim into the sub-threshold region, because then you'll get very strange behavior like flicker and things like that. So that's the difference. LEDs start from zero and then go up and up. But there is an L shaped curve for lasers. It's a subtle difference but meaningful if you're trying to modulate the part.

LED professional: That means that if I need a dimmer solution for a general lighting application, I always have to use a modulated signal.

Julian Carey: Yes, that's right. It's an interesting but subtle point.

LED professional: Since lasers are used in so many really fast applications that you would have a very high frequency for that and then you could avoid the unwanted effects.

Julian Carey: You're right. And response times for lasers are very, very fast and so, a future area of development or at least conceptual exploration right now is LiFi and how lasers could contribute to communication over line of sight. Either vehicle to vehicle or within the built environment. The laser portion - the blue portion - can be modulated extremely fast.

LED professional: But isn't phosphor slowing it down?

Julian Carey: Yes, it is.

LED professional: One more question about the road map. What will we see next year?

What will we see two years from now? What will happen later on?

Julian Carey: We have two roadmaps: Automotive and Specialty Lighting. Next year, I guess, in automotive we'll see an increase in lumens to the fiber module architecture. So maybe a 1000 lumen source next year and a 2000 lumen source the following year coupled with dynamic capabilities. Most of the work right now is going into integrating an ultra-bright source into dynamic reflectivity and optics. So that's what we'll see, probably late 2019, if not the following year: Dynamic architectures that combine laser, phosphor, high intensity lighting, but also with MEMS mirrors and LC optics that can shift the beam pattern.

For specialty lighting, next year, we should also see a 1000 lumen SMD and within one to two years we should see a 4000 Kelvin shift of the whole product line. Those are the kind of main priorities. And that's enough work!

LED professional: If you move that fast in your developments, how large is the proportion of researchers and developers in your company?

Julian Carey: I would say, that out of 120 people, we still have, as far as R&D and product development go, probably about eighty people - or two thirds of the company. We don't have an extensive sales and marketing department. We're not like companies like Osram or Lumileds at this point. We have about four people around the world that work with our customers. But now we're increasing the size of our operational group, which has been very small until the last three or four months. Now we need to coordinate a lot of production - bringing that discipline and control to the process rather than being solely R&D. We have to make way for "the same way every day" rather than "a different way every day", which is what we've done up until now.

LED professional: Thank you very much for providing these really interesting insights into laser technology!

Julian Carey: Thank you for the opportunity to talk about these topics!.

Hermetic Polymer-Free White LEDs for Harsh Environments

AlGaInN-based white LED can easily achieve lifetimes of up to 100,000 h depending on junction temperature and current density. However, state of the art silicone encapsulated LEDs with powder-based phosphors reveal a strong dependence of field lifetimes on environmental conditions such as humidity, corrosive gas and air pollutant exposure. Dr. Michael Kunzer, Group Leader LED Modules at Fraunhofer Institute for Applied Solid State Physics and his colleagues, Ralf Schmidt, Andreas Zibold, Vasileios Georgiou-Sarlikiotis, Michael Arnold and Isabel Kinski propose luminescent ceramics as an interesting alternative to polymer-dispersed phosphors. This provides entirely new opportunities for the manufacturing of white LEDs. The authors explain the properties and advantage of this hermetic, light converting cap material and how to completely avoid polymers.

White LEDs can achieve lifetimes of several 10,000 h depending on junction temperature and current density. However, state of the art polymer-encapsulated LEDs with powder-based phosphors reveal a strong dependence of field lifetimes on environmental conditions such as humidity, corrosive gas and air pollutant exposure. An interesting alternative to polymer-dispersed phosphors are luminescent ceramics. The development of such ceramic phosphor wafers for LED conversion with diameters of up to 100 mm is demonstrated. They can be manufactured impermeable, provide a 30 times higher thermal conductivity and are chemical, mechanical and temperature resistant.
To facilitate this, Fraunhofer has developed high-power LEDs which use luminescent ceramics as hermetic, light converting cap material. Since pollutants cannot penetrate inside and give rise to corrosion, a direct application of these new LEDs without elaborate external housing in chemical burdened environments is possible. As a further advantage the inevitable heat generated by the light conversion is dissipated through the thermally conductive ceramics itself, rather than further burdening the LED chip. This allows high ambient temperature operation. Furthermore, the developed wafer-level package technology allows long device lifetimes with low color drift by completely avoiding polymers.

Introduction

Thermal issues

During the last few years phosphor conversion white light emitting diodes (LEDs) based on the AlGaInN-thin-films [1] have replaced traditional light sources in most lighting applications with market shares of up to 80%. Under optimal conditions these white LEDs can achieve lifetimes of up to 100,000 h [2] depending on junction temperature and current density. However state of the art silicone encapsulated LEDs with powder-based phosphors reveal a strong dependence of field lifetimes on environmental conditions such as elevated operation temperature, humidity, corrosive gas and air pollutant exposure.
The reason behind this is the design of current white LEDs. They consist of blue light emitting chips and yellow phosphor, which is excited by the blue light and in total produces white light. The yellow phosphor powder is dispersed in a polymer or silicone matrix with low thermal conductivity either placed in a layer directly on, or in a lens above the chip [1]. The packaging of a standard white converter LED is shown in figure 1.

Continuous improvements of the LED chips enable increasing current and luminance densities, which lead to an extreme photo-thermal strain on the phosphor powder and the surrounding polymer matrix even without external influences. This is particularly enhanced since the stoke-losses in the phosphor, when converting blue to yellow light, are unavoidable and the chip surface on which the phosphors settle is already the hottest area in the LED device.

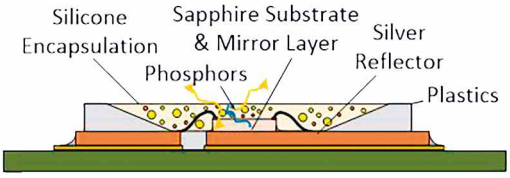


Figure 1:
Schematics of a traditional white MID-power LED in plastic package with phosphor powder in silicone matrix

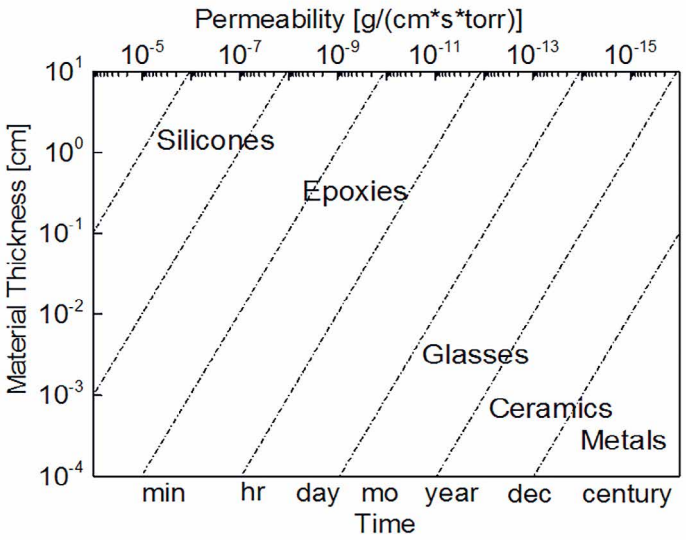


Figure 2:
Helium permeability of different packaging materials over time and thickness [8]

Gas permeability of LED packaging materials

Gas permeability and inertness are important factors for encapsulation and packaging materials. The He gas permeability of different materials over time and versus material thickness is shown in figure 2 for materials commonly used in opto- and microelectronic packaging. The pollutant has to diffuse through the encapsulation first, before being able to reach the silver reflector, p-contact or converter. Thus, the encapsulation should be as impenetrable to gases as possible. Phenyl-and methyl-based silicones are widely used as encapsulation materials for LEDs. Phenyl-based silicones offer a ten times lower gas permeability and at the same time a higher optical index than methyl-based silicones, which facilitates light extraction of the generated light. Methyl-based silicones are general purpose encapsulation materials and are used because of their lower price compared to Phenyl-based Silicones. Epoxy is also used as an encapsulation material. It shows lower gas permeability and a high thermal stability but its low optical index is unfortunate for an LED encapsulation material since this reduces the light extraction efficiency [3]. On the other hand, glasses, ceramics and metals have an up to 10 orders in magnitude lower gas permeability which facilitate true hermetic operation.

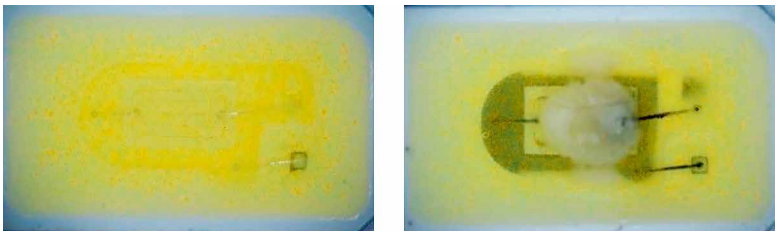


Figure 3:
Degradation of a mid-power LED due to operation in pure air (left) and in air with 10 ppm H_2S trace gas (right). The diffusion of the corrosive trace gas causes a darkening of the metal reflector and a clouding of the silicone matrix above the chip [6]

Effects of trace gases and air pollutants on LEDs

The presence and concentration of air pollutants depend on the application. Especially lighting applications in the heavy and chemical industry, harsh environments, automotive, agriculture and pools can be affected. Also, applications where one would not suspect an accelerated degradation might be concerned, since critical chemical substances are ubiquitous. They are even found to accumulate in the luminaire assembly itself, especially if sealed, since cables and electric components can leak out gases during operation. Penetrating pollutants can accelerate browning and corrosion inside the LED package [4, 5]. This can reduce the lifetime, cause light losses inside the package and cause color shifts that the eye can easily recognize when comparing different LEDs. The silver-based reflectors inside the package and the LED chip itself are particularly sensitive in this respect. For example, the effects of the corrosive pollutant H_2S on a mid-power LED with silicone encapsulation are discussed below [6, 7]. In the upper part of figure 3 a mid-power LED operated in room temperature air for 380 h is shown. When the device is operated under the same conditions in air with 10 ppm H_2S trace gas a severe darkening of the metal reflector and the bond wires is observed. Furthermore, the silicone matrix above the chip is clouded. For this particular LED a 70% light loss is measured.

Figure 4: Photograph of translucent YAG:Ce ceramics with 0.5 mm thickness and different content of Ce doping; (a) laying and (b) standing on the background [16]

Figure 5: Color and brightness distribution of a 100 mm YAG:Ce ceramic phosphor wafer in a test setup with 460 nm back-illumination

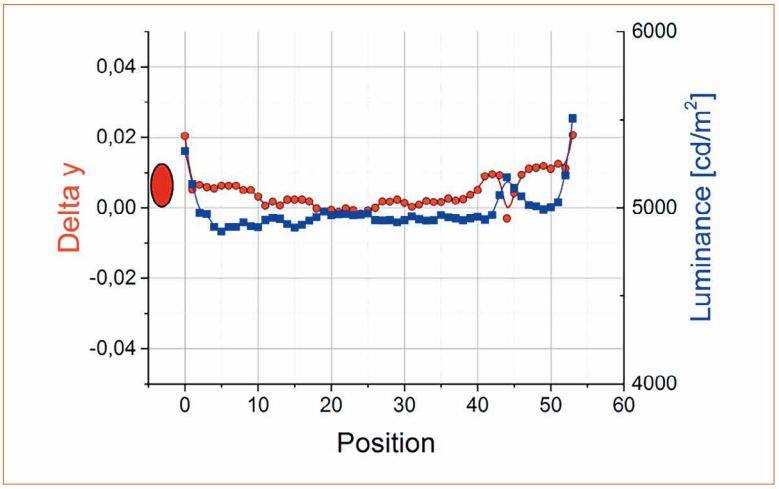


Figure 6: Lateral color coordinate drift ΔCCY (red) and luminance distribution (blue) across a 100 mm ceramic phosphor wafer. Compared to a three-step MacAdams ellipse only a small min-max color drift of ΔCCY < 0.01 is observed

Ceramic Phosphor Development

To solve the problem of thermal degradation, an entirely inorganic converter with a high thermal conductivity is in the focus of research and development. One approach to prepare such a converter is to sinter a polycrystalline ceramic based on YAG phosphor powder [9, 10]. Polycrystalline YAG ceramics for optical application were described first by Ikesue et al.[11] in the middle of the 1990s by mixing Al_2O_3 and Y_2O_3 powders using vacuum sintering. These first ceramics were clearly transparent with about 80% transmittance for visible light without any dopant. In the following years, the YAG was doped with neodymium and the resulting ceramics were used as laser material with properties comparable to YAG:Nd single crystals [12]. Nowadays, instead of phosphor-in-silicone composites, polycrystalline YAG:Ce ceramics, with different levels of transparency, mounted on top of a blue-emitting LED are described for high-power white LEDs [13]. Compared to the phosphor-in-silicone composites the ceramic phosphors have a lower concentration of the expensive cerium dopant, and in addition, exhibit excellent optical and thermal stability. The optical properties and the content of scattering centers can be engineered by varying the degree of porosity, the grain structure, and the minority phases [14]. But the main advantage compared to silicone-based converters is the high thermal conductivity of the ceramic (>5 W/mK) that allows an efficient dissipation of the heat caused by the Stokes losses within the phosphor, thus diminishing the thermal effects on the optical performance. Most recently, the optical properties of transparent, polycrystalline YAG:Ce ceramics were discussed in the literature and Raukas et al. [14] described that the intrinsic scattering by pores induces backscattering, thus leading to absorption within the converter or the LED chip, which should be reduced to achieve a maximum optical conversion efficiency (CE). On the other hand, scattering is required for a homogeneous mixing of transmitted blue and converted yellow light and can be achieved by extrinsic scattering at a rough or structured surface. In combination with a blue (460 nm) LED and under the requirement that 35 percent blue is transmitted to create white light with 5000 K color temperature, the calculated theoretical maximum optical-optical down conversion efficiency is 283 lm/Wopt [13]. The result published in the literature for the luminous efficacy of a 0.63 mm thick YAG:Ce ceramic disk with 0.1 mol% Ce doping was 73.5 lm/W for the complete LED [15]. The transmittance of this ceramic was about 70 percent in the visible range with a 10% transmittance in the blue absorption band at a wavelength of 460 nm and a grain size of about 10 µm with residual pores on the grain boundaries. The data published so far in the literature report on whether the thickness of the specimen or the concentration is a crucial factor, but the data are mostly not clearly comparable and seem to depend on the individual properties, such as increased optical path length due to pore scattering, of the specimen. To study the influence of dopant concentration and sample thickness, our ceramics have been applied as converters in conjunction with a blue LED and the effects of concentration as well as the thickness of the polycrystalline disks on the optical properties of the resulting PC LEDs have been investigated [16].

The yttrium-aluminum garnet ($Y_3Al_5O_{12}$, YAG) polycrystalline disks were prepared by reaction sintering of yttria (99.99%), alumina (99.999%), and cerium oxide (99.995%) in a ratio of Y:Al of 3:5 and with an addition of a different concentration of cerium oxide of 0.1, 0.5, or 1 mol% percent as well as a sintering aid (tetraethyl orthosilicate) under vacuum at a temperature of 1800°C for 5 h in a furnace with molybdenum lining. The powder mixtures were pressed uniaxially at about 50 MPa and cold isostatically at about 700 MPa to form cylindrical disks. The resulting polycrystalline bulk disks were

grinded and polished to the required thickness of around 0.4 mm, depending on the amount of scattering. The microstructure of the completely densified ceramics was dominated by the main phase of $Y_3Al_5O_{12}$ with less than 10 µm grain size. The scattering effect of the translucent ceramic is the result of a secondary phase of alumina located at the grain boundaries. Further details on the preparation, the microstructure and the optical properties are described elsewhere [16].

In order to facilitate wafer-level packaging using large-sized ceramic phosphor wafers the sintering, condensation and wafering process has been scaled up to demonstrate ceramic phosphor wafers with a diameter of 100 mm. An important measure for production yield and LED color binning is the optical homogeneity of the phosphor wafer. To measure the lateral color and brightness distribution the ceramic phosphor wafer was exposed to a homogenous 460 nm LED back-illumination. The resulting color and brightness distribution are shown in figure 5. The CIE 1931 color coordinates x and y as well as the luminance has been measured across the wafer using a compact spectral radiometer (Figure 6). Compared to a three-step MacAdams ellipse only a small min-max color drift of $\Delta CCY < 0.01$ is observed. Furthermore, the luminance distribution is very stable across a 100 mm ceramic phosphor wafer.

Different methods such as volume scattering and laser surface µ-structuring have been applied to remove wave-guiding and the angular color distribution in the far-field pattern. An example of a Laser surface µ-structure prepared by ultra-short-pulse UV ablation in a YAG:Ce phosphor wafer is shown in figure 7. The structure provides extraction facets to avoid light guiding of the yellow light generated inside the phosphor and to improve the angular far-field pattern. Furthermore, specific dielectric filter and anti-reflection layers have been utilized to improve the conversion efficiency of the phosphor and to reduce light losses and unwanted reflections.

Polymer-Free Full Ceramic LED Fabrication

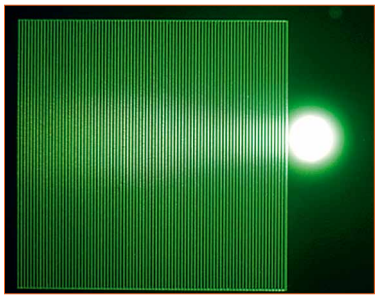


Figure 7:
Laser surface µ-structure in a YAG:Ce phosphor wafer. The structure provides extraction facets to avoid light guiding of the yellow light generated inside the phosphor and to improve the angular far-field pattern

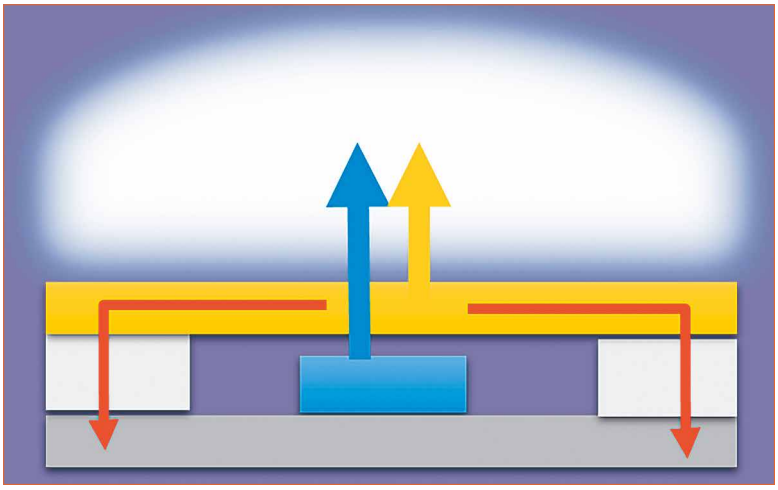


Figure 8:
Schematics of the hermetic full-ceramic LED. The phosphor is recessed from the LED chips and forms a part of the package

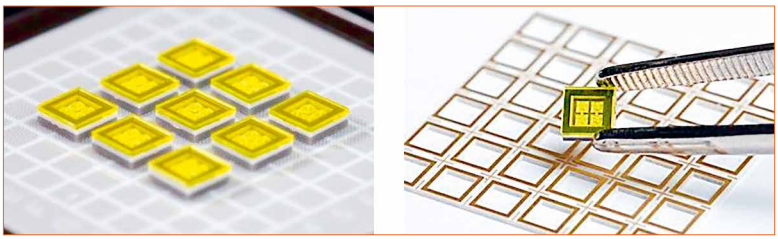


Figure 9:
Hermetic high-power 4 × 3 W full ceramic white LED in SMT package with 4.2×4×1.5 mm device dimensions

Ceramic phosphors are already used in LED production [13] as chip-level converters which are polymer-bonded on the LED chip and silicone encapsulated. In this work the intention is to demonstrate power-LEDs where the ceramic phosphor wafer is part of the package and is thermally isolated from the LED chip, providing no further thermal burden. Instead the good thermal conductivity of the ceramic phosphor is used to cool of the heat generated by stokes-losses via the package directly into the heat sink. Furthermore, the hermitic nature of the ceramic phosphor is used to form a hermetic polymer-free LED package. To avoid polymer in the package and to achieve hermeticity all parts of the package are eutectic bonded.

The fabrication of the LEDs is based on a wafer-level process with a highly thermal conductive Aluminum nitride interposer wafer, a highly reflective Aluminum oxide spacer and the ceramic phosphor wafer on top. A total of four 3 W power flip-chips are bonded inside the cavity. The outer dimensions of the SMT devices are 4.2×4×1.5 mm (Figure 9).

LED Device Characterization

Extensive optical characterization has been performed on the LED devices to improve the conversion efficiency of the phosphors, to improve the blue emission of the pump flip-chips and to reduce absorption and reflection losses within the package. The luminous efficacy of the polymer-free LED for different drive currents are shown in figure 10. A maximum efficiency of more than 140 lm/W is achieved a low current with 125 lm/W at a drive current of 350 mA. Although this

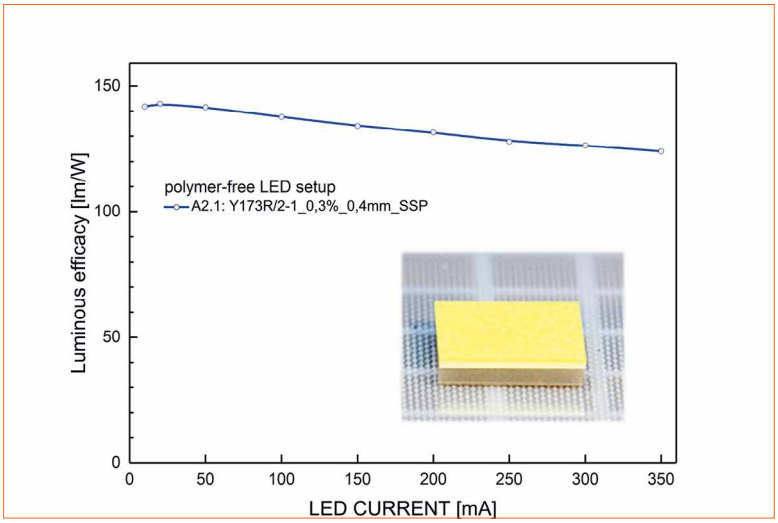


Figure 10:
Luminous efficacy vs. LED drive current of a polymer-free full-ceramic LED

efficiency is commonly achieved with polymer-packaged LEDs it is a very high value when compared to conventional hermetic LEDs in TO-can package.

Conclusions

Lighting applications in demanding, hot, harsh, polluted or corrosive environments reduce the useful lifetime of conventional LEDs in polymer-package. This is due to the low thermal stability of polymers and their permeability to gases. For such applications, hermetic polymer-free LEDs have been demonstrated in this work. The LEDs are based on ceramic phosphor which is part of the package. The rest of the package is also full ceramic with eutectic bonding of the individual parts. A SMT device with 4×3 W electrical power and a footprint of 4.2×4.2 mm has been demonstrated. A high luminous efficacy of 125-140 lm/W has been achieved. ■

Acknowledgements:
We sincerely thank our colleague Thorsten Passow for scientific discussions and Mrs. S. Liu for electrical-optical LED characterization. This work was financially supported by the Ministry of Science, Research and Art Baden-Wuerttemberg (MWK) through the Sustainability Center Freiburg within the Pilot project "SusLight". The ceramic LED phosphor and package development was funded by Fraunhofer within the WISA Projekt HeraKLED.

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New Approach for Accurate and Fast Measurement of LEDs T_j

Junction temperature of LEDs is one crucial parameter to being thoroughly observed. In this paper, Ahmet Mete Muslu, Onuralp Isil and Prof. Mehmet Arik from the Energy Efficient Electronics and Lighting Technologies Center (EVATEG), Department of Mechanical Engineering at the College of Engineering Ozyegin University will at first describe the importance of T_j for LED systems including RGB and white LEDs. Then they will present techniques from literature and recently in-house developed novel methods and a new Junction Temperature Measurement Device (EVAtherm). Results in selected general lighting and automotive lighting applications will be demonstrated.

Although LEDs offer unique advantages, excessive heat generation and the rise in the junction temperature result in a significant drop in efficiency, lifetime and the light output of LED chips. While the determination of junction temperature is very critical to characterize the performance of LEDs, junction temperature measurements with current systems pose some challenges, such as high uncertainties, high cost leading to limited affordability, and limited user functions. Thus, development of a novel junction temperature measurement device that offers fast and accurate results with cost-effective solutions is needed for companies aiming for developing future lighting technologies.

This article introduces an in-house developed junction temperature measurement device with a number of unique advantages. In order to show the functionality of the device, the impact of junction temperature over optical and electrical properties of high power RGB LEDs is investigated in the current study and the measurement system is introduced. Results show that junction temperature of RGB LEDs can be easily and quickly measured with high accuracy.

Introduction

After many years of use, traditional lighting sources are rapidly replaced by LEDs (light emitting diodes), which offer high efficiency, long lifetime, environmentally friendly use, high durability and various color options [1, 2, 3]. However, LEDs have some limitations just like all other electronics, and thermal problems caused by heat generation over the junction region of LEDs are among the most important. As observed in almost all electronics, only a portion of the electrical energy applied to the LEDs can be used and the remaining energy (around 70%) is lost as heat and causes the increase in junction temperature [4]. This temperature increase leads to a drop in the performance and lifetime of the LEDs. As a result of experimental findings, it was concluded that if the junction temperature of LEDs is kept under some limits, long life span as much as 50,000 hours can be provided by LEDs [5]. Therefore, it is very important for professionals both in industry and academia to address thermal issues in LED products by conducting accurate measurements of the junction temperature of LEDs.

The current junction temperature measurement systems operate based on the transient

measurement technique [6, 7, 8]. However, in recent years, global users who want to measure the junction temperature find these products very expensive and their feedback in terms of the reliability of the measurements raise some concerns. Therefore, in order to realize thermal characterization of LED products, there is a need for a junction temperature measurement system that offers accurate, reliable, fast and inexpensive solutions to the parties in industry and academic environments.

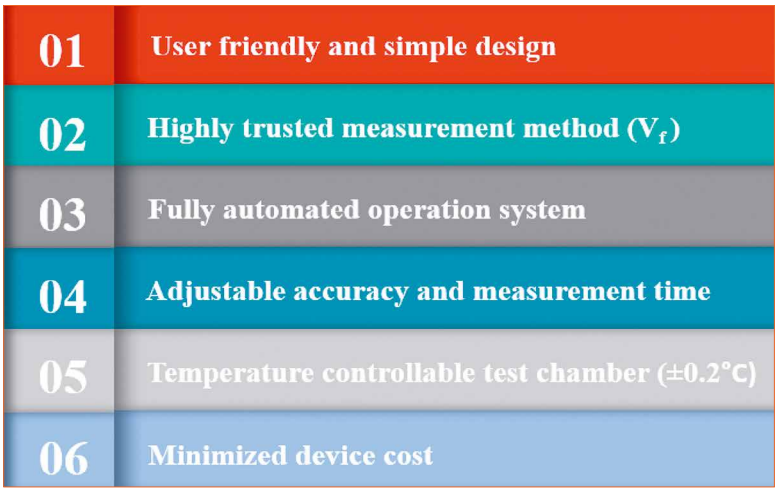


Figure 1:
Various advantages offered by the novel junction temperature measurement device

Junction temperature measurements of existing measurement devices on the market rely on layer by layer determination of the thermal characteristics of an LED package. In these products, thermal capacity and thermal resistance values of different LED components are determined [9]. The first step for thermal resistance measurement is to obtain the time dependent heating curve of the LED. In this method, sampling and data collection speed of the device should be quite high in order to obtain the heating curve of the LEDs. At the same time, high measurement frequency and accuracy is required since complex calculations such as convolution, inversion and Fourier transform are required for the calculation of the structure function, which defines the relationship between thermal resistance and thermal capacity.

Measurement devices based on the transient measurement technique produce information including thermal resistance, heat flow path, properties of thermal interface material first, other than measuring the junction temperature directly. As a result of the complexity of the device, the increased cost makes these products quite expensive. In fact, high sampling rate and data acquisition resolution of these devices are more than necessary for users who want to measure the junction temperature only [10]. In the study, it is stated that a 1 ms resolution time is ideal for junction temperature measurements of an LED package.

In addition, the measurement results obtained using the transient measurement technique is based on the one-dimensional heat flow path assumption in the LED package. However, the presence of LED components such as phosphors and lens often interfere with the symmetrical spread of the heat flow [10, 11] and the junction temperature measurements with one-dimensional assumption may not be reliable, especially for white LEDs and LEDs with an asymmetric structure. In addition, since the actual thermal resistance is obtained by determining heat generation in the package with the subtraction of radiant power from electrical input power, radiometric systems are needed to determine radiant power of LEDs and thermal resistance of the package. Therefore, the thermal resistance values determined without radiometric measurements can be defined as a reference thermal resistance other than the actual one [10]. Measurement devices that do not incorporate the radiometric measurements of LEDs are suspicious in terms of characterizing thermal resistance of LED packages.

The measurement system developed by the EVATEG Center does not have the requirements for time-dependent measurements, and the thermal resistance versus thermal capacitance calculations. Instead of short-term based measurements, the calibration measurements performed in a stable and thermal equilibrium condition eliminate the costly processes of the previous devices. In this respect, instead of a duration of 1 µs, measurement data is collected with a sampling rate of 1 ms. The suitability of this timing has also been demonstrated in an earlier study conducted at the EVATEG Center [12]. Since the measurements do not focus on direct determination of thermal resistance, applications that increase the measurement uncertainty such as determining the thermal conductivity of the thermal interface material are also avoided. In addition, since junction temperatures of LEDs are measured with the forward voltage values obtained in the steady state and thermal equilibrium conditions, one dimensional (1D) heat flow assumption is not made. In this respect, junction temperature, which is the main parameter of interest for the LEDs is measured reliably and automatically without increasing the cost.

Description of the New Junction Temperature Measurement System

In many industrial applications, thermal characterization and performance evaluation of LEDs are done by measuring the temperature of the nearest solder point on an electronic card instead of junction temperature. Since the optical behavior is directly influenced by the junction temperature, evaluations of performance, light and color properties and lifetime based on

Figure 2:
Working capabilities of the developed junction temperature measurement device

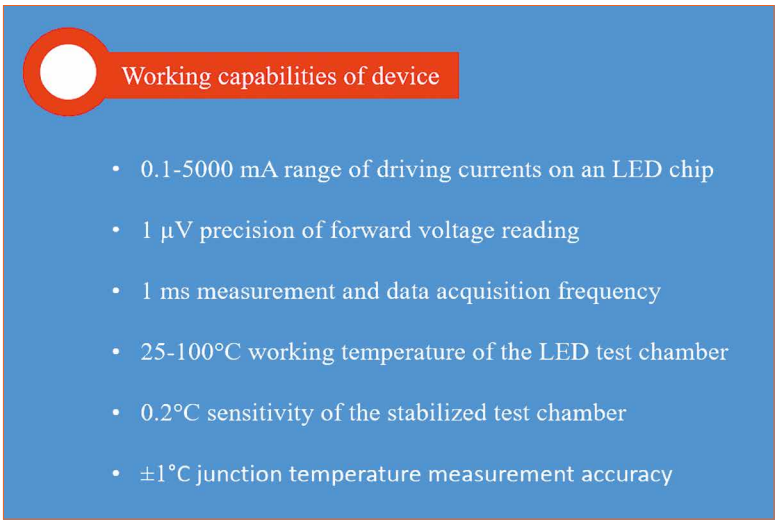


Figure 3:
Graphics of the system with RGB LEDs inside the test chamber

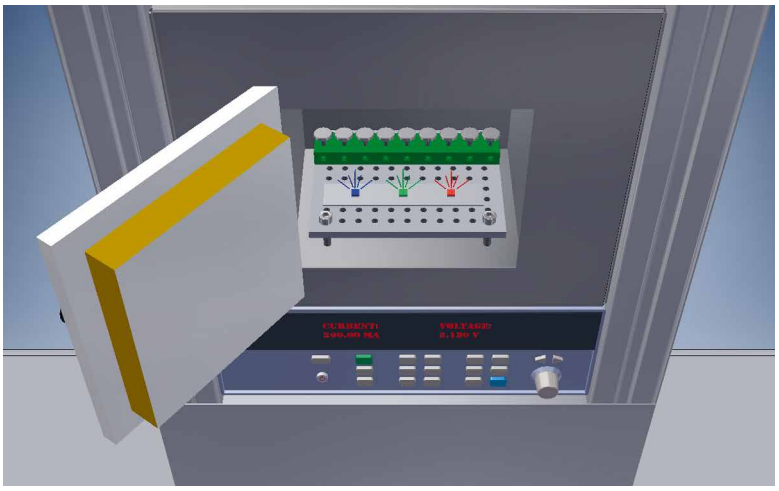
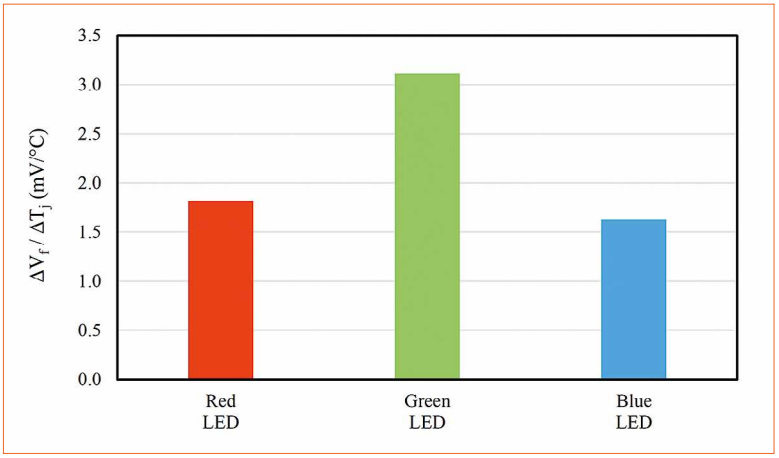


Figure 4:
Forward voltage drop behavior of RGB LEDs with junction temperature



the solder point temperature cause considerable errors. On the other hand, companies using systems that can measure junction temperature in a less costly and reliable manner will make a big difference on an international scale in terms of product quality and measurement reliability, considering the rapidly increasing number of energy efficiency related projects. With this in mind, EVATEG Center produced a novel junction temperature measurement device for various parties in the sector who are LED manufacturers, designers, optical engineers and users who wish to perform thermal and optical characterization of LEDs for any reason. In this sense, lighting, automotive, TV, tablet and electronics manufacturers come to the fore.

It is strongly believed that the introduced device will fill a significant gap in the market. In fact, a significant reduction in cost of the measurement device will enable many companies in the lighting and electronics industries to access the device and improve the performance of their products. This device will also greatly contribute to energy savings because it sheds light on the performance parameters of LEDs. Compared to commercially offered systems, this high-quality device in terms of price and performance will provide new opportunities for many international companies to develop high-performance technologies.

Considering the operation technique, the new system quickly determines the relationship between the junction temperature and the forward voltage of an LED chip at the steady state and thermal equilibrium conditions in the first phase of the measurements. Then, the junction temperature of an LED chip operated at a certain driving current is measured without making a one-dimensional heat flow assumption [13]. This is very important since the LED chip and package designs as well, push towards higher lumen extraction driven by higher electrical current conditions and result in 3D heat transfer at the LED chips. Therefore, 1D assumption will produce high uncertainties and may lead to catastrophic system failures. In all steps, the measurements will be performed without requiring any intervention by the user. In addition, the measurement accuracy of a test can be adjusted by the user, and this gives a user a considerable amount of flexibility. In this sense, a user can set the required test conditions in a measurement including ambient temperature in the test chamber, sensitivity of chamber temperature and forward voltage readings of LEDs, pulse and driving currents etc. Thus, depending on the limitations for measurement time, the user can adjust the measurement conditions to ensure fast and accurate measurements.

In this way, the desired linear relationship between the junction temperature and forward voltage is provided in the measurement software. The measurement unit and the measurement capabilities are given respectively in figure 2 and figure 3.

In order to demonstrate the functionality of the introduced device, the performance of high-power red, green and blue (RGB) LEDs was evaluated with the junction temperature measurements conducted in it. Change in forward voltage and electrical power with junction temperature, the drop of conversion efficiency and lumen per watt value of LEDs with driving current and junction temperature are examined in the next section to show the intended use of the current system.

Results and Discussions

Commercial red, green and blue high power LEDs (CREE XLamp XP-E2 [14]) were used to observe junction temperature behavior of LEDs and its interactions with optical and electrical properties. Measurements were initiated with the calibration of RGB LEDs in the system and the calibration equations were derived to create a relationship between junction temperature and forward voltage for each LED type. Calibrations tests were conducted at various steady state temperatures of the test chamber and LEDs were pulsed with 1 milliampere (mA) current for 1 millisecond (ms) to determine the corresponding forward voltage values at various chip temperatures of LEDs without causing considerable heat generation over the junction region of LEDs. Comparison of RGB LEDs in terms of junction temperature versus forward voltage drop behavior was made with the calibration results as seen in figure 4. As a result, it has been determined that the highest drop in forward voltage is observed in green LEDs while the blue LED has a little less change in forward voltage compared to the red LED.

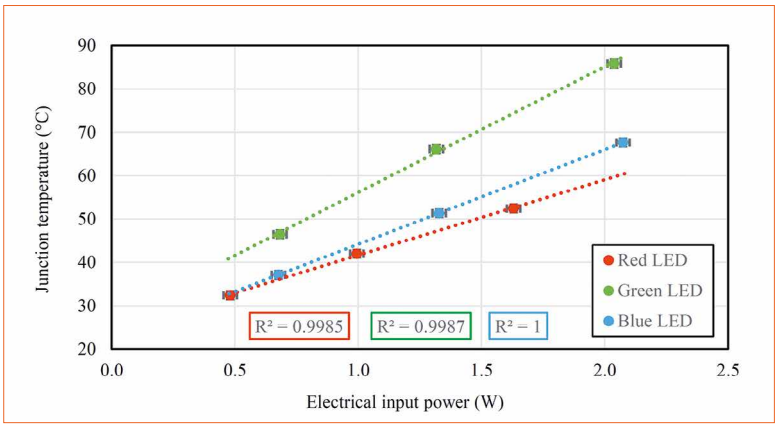


Figure 5:
The change in junction temperature of RGB LEDs with electrical input power

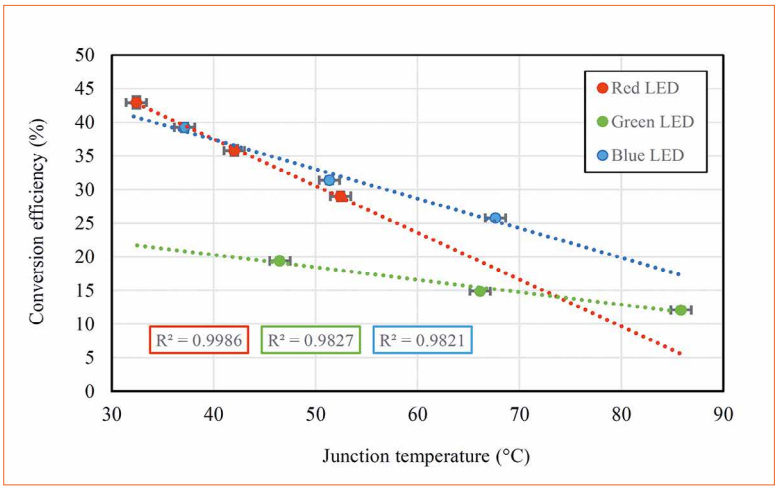


Figure 6:
Change in conversion efficiency of RGB LEDs with junction temperature

After characterizing the variation of junction temperature with forward voltage of LEDs, junction temperature measurements were conducted for each LED at the steady state condition for driving currents of 200, 350 and 500 mA. When steady state is reached, driving currents were shifted to 1 mA for 1 ms duration and the corresponding forward voltage was read and plugged into the calibration equations to determine junction temperature at each driving current. Electrical input powers at each operating current were also determined for RGB LEDs at the steady state condition. The change in junction temperature with electrical input power is shown in figure 5 for each LED type.

It is observed that green and blue LEDs show a similar behavior in terms of forward voltage at three driving currents; thus, very close electrical input powers were measured for green and blue LEDs. However, junction temperature measurements have shown that heat generation over junction region of green LEDs is significantly higher than the blue LEDs. Therefore, it can be understood that thermal issues arisen in green LED packages are more critical compared to the blue LEDs and better cooling solutions need to be developed since the optical properties are critically affected.

On the other hand, the forward voltage values of red LEDs are significantly lower at the same driving currents (200, 350 and 500 mA) in comparison with green and blue LEDs. Despite the significant difference in electrical input powers, the junction temperatures of red LEDs are slightly lower than blue LEDs. Thus, it can be said that blue LEDs are operating more efficiently considering the overall range of electrical input powers.

After understanding the forward voltage and electrical input power behavior of LEDs with junction temperature, the alteration of

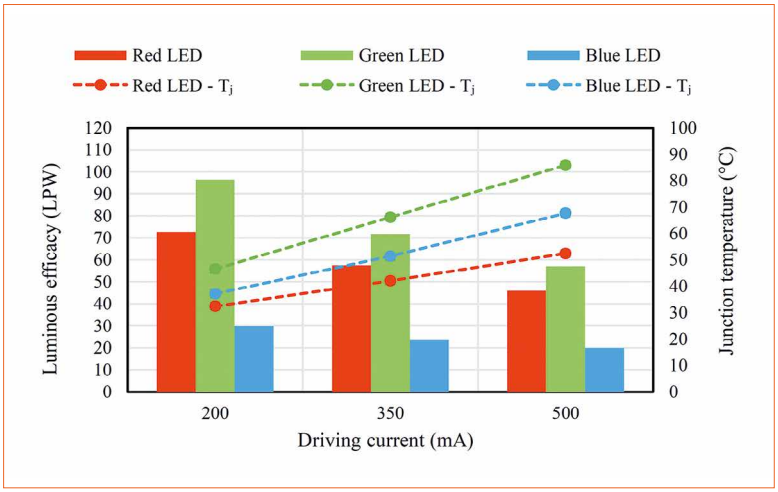


Figure 7:
Thermal, optical and electrical characteristics of RGB LEDs at three driving currents

conversion efficiency with junction temperature was investigated for RGB LEDs. Conversion efficiency of LEDs refers to the fraction of total radiant power to the electrical input power of LEDs. Thus, an Integrating Sphere System was utilized in order to measure the total radiant power of LEDs operating in steady state conditions at 200, 350 and 500 mA currents. The relationship between junction temperature and conversion efficiency of RGB LEDs was created as shown in figure 6. It is found that conversion efficiency of red LEDs is slightly higher at junction temperatures below approximately 40°C while blue LEDs are more efficient at electrical conditions of their standard use. In addition, conversion efficiency of green LEDs is expected to be higher than red LEDs at junction temperatures over 74°C. As a result, conversion efficiency of red LEDs is most affected by the change in junction temperature.

Thermal, optical and electrical interactions of RGB LEDs are also characterized in figure 7 at driving currents of 200, 350 and 500 mA. Since a higher lumen output is always desired by LED users, it is critical to understand how LPW value of RGB LEDs is affected by junction temperature. The results have shown that lumen per watt values of LEDs are reduced by around 37%, 41% and 33% respectively for red, green and blue LEDs as the operating current is increased from 200 mA to 500 mA. It was also realized that although the highest junction temperatures are measured in green LEDs, the highest lumen outputs are also obtained with green LEDs. This shows that if green LEDs are cooled effectively, the blue LEDs which are composed of the same semiconductor material as green LEDs may be replaced by green LEDs in applications where similar functionality is required.

Summary and Conclusions

In this study, an in-house developed junction temperature measurement device was introduced and thermal, optical and electrical characterization of RGB LEDs performed in this system are demonstrated. Compared to commercially offered alternative systems, high prices ranging from 50,000 to 150,000 USD, the EVAtherm is a product that can be reached by a broad audience of scientists, engineers and companies with an approximate price of 40,000 USD and it will offer fast and reliable junction temperature measurements for LEDs. Thus, optical engineers, scientists and other professionals using this system will be able to characterize thermal performance of their photonic devices. With the reliable thermal data, they will have a chance to address thermal issues of their products and improve their performance in terms of thermal, optical and electrical characteristics.

In the study, junction temperature measurements of RGB LEDs give significant insights about how forward voltage drop, electrical input power, conversion efficiency and luminous efficacy values of LEDs are affected by heat generation over the junction. The differences in results are attributed to the use of different active layers in RGB LEDs. It has been shown that all optical and electrical traits of LEDs are negatively affected by the rise in junction temperature and there is a significant potential to improve the performance of LEDs considering the highest conversion efficiency of 32% for blue LEDs at the nominal driving current (350 mA). Thus, it is strongly believed that the proposed measurement system in this study will contribute to the development of highly efficient systems of future lighting technologies. ■

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LiFi as a Paradigm-Shifting 5G Technology

There are many misconceptions about LiFi, a wireless communication technology that uses the infrared and visible light spectrum for high speed data communication. Prof. Harald Haas, Professor of Mobile Communications at the Institute for Digital Communications from the University of Edinburgh, will explain what Light-Fidelity (LiFi) is and argue why it is a 5th Generation (5G) technology. Peak transmission speeds of 8 Gbps from a single light source have been demonstrated, and complete cellular networks based on LiFi have been created. Besides discussing numerous misconceptions, the potential impact this technology can have across a number of existing and emerging industries will be explained as well as new applications that LiFi can unlock in the future.

In this paper we argue that the optical spectrum could transform wireless network in a similar way and why it has transformed wired communication networks with the advent of fiber-optical communication. Peak transmission speeds with off-the-shelf light emitting diodes (LEDs) of 15.7 Gbps have recently been demonstrated. We will explain how these advances will be used to build full wireless networks which support user mobility. We discuss numerous misconceptions and use cases. Lastly, we illustrate the potential impact this technology may have on new and emerging industries.

Introduction

LiFi is a wireless communication technology that uses the infrared and visible light spectrum for high speed data communication. LiFi, first coined in [1] extends the concept of visible light communication (VLC) to achieve high speed, secure, bi-directional and fully networked wireless communications [2]. It is important to note that LiFi supports user mobility and multiuser access. The size of the infrared and visible light spectrum together is approximately 2,600 times the size of the entire radio frequency spectrum of 300 GHz (Figure 2). It is shown in [3] that the compound annual growth rate (CAGR) of wireless traffic has been 60% during the last 10 years. If this growth is sustained for the next 20 years, which is a reasonable assumption due to the advent of Internet-of-Things (IoT) xK-TV and machine type communication (MTC), this would mean a demand of 12,000 times the current bandwidth assuming the same spectrum efficiency. As an example, the industrial, scientific and medical (ISM) RF band in the 5.4 GHz region is about 500 MHz, and this is primarily used by wireless fidelity (WiFi). This bandwidth is already becoming saturated, which is one reason for the introduction of Wireless Gigabit Alliance (WiGig). WiGig uses the unlicensed spectrum between 57 GHz - 66 GHz, i.e., a maximum bandwidth of 9 GHz. In 20 years from now, the bandwidth demand for future wireless systems would however, be 12,000 × 500 MHz which results in a demand for 6 THz of bandwidth. The entire RF spectrum is only 0.3 THz. This means a 20 times shortfall compared to the entire RF spectrum. In comparison, the 6 THz of bandwidth is only 0.8% of the entire IR and visible light spectrum. One could argue that a more aggressive spatial reuse of frequency resources could be adopted to overcome this looming spectrum crunch. This approach has been used very successfully in the past and has led to the 'small cell concept'. In fact, it has been the major contributor towards the improvements of data rates as illustrated in figure 1. The cell sizes in cellular communication have dramatically shrunk. The cell radius in early 2G systems was 35 km, in 3G systems 5 km, in 4G systems 100 m, and in 5G probably about 25 m in order to reuse the available RF spectrum more efficiently and to achieve higher data densities.

However, further reductions in cell sizes are more difficult to achieve due to the high infrastructure cost for the backhaul and fronthaul data links which connect these distributed access points to the core network. Moreover, with a smaller cell size the likelihood of line-of-sight between an interfering base station and a user terminal increase. The resulting interference can significantly diminish data rates and may cause a major problem in cellular networks [4]. Therefore, WiFi access points have been mounted under the seats in stadia to use the human body as an attenuator for the RF signals and to avoid line-of-sight interference links. Clearly, this is not a viable solution for office and home deployments. For these reasons, it is conceivable that the contributions for the future mobile data traffic growth will stem from more spectrum rather than spatial reuse. In particular, the optical resources are very attractive as they are plentiful as shown in figure 2 and they are license-free.

These resources can be used for data communication which is successfully demonstrated for decades in fiber-optic communication using lasers. With the widespread adoption of high brightness light emitting diodes (LEDs) an opportunity has arisen to use the visible light spectrum for pervasive wireless networking.

Traditionally, a VLC system has been conceived as a single point-to-point wireless communication link between a LED light source and a receiver which is equipped with a photo detection device such as a photo detector (PD). The achievable data rate depends on the digital modulation technology used as well as the lighting technology. The available lighting technologies are summarized in figure.

Most commercial LEDs are composed of a blue high brightness LED with a phosphorous coating that converts blue light into yellow. When blue light and yellow light are combined, this turns into white light. This is the most cost-efficient way to produce white light today, but the phosphor color converting material slows down the frequency response, i.e., higher frequencies are heavily attenuated. Consequently, the bandwidth of this type of LED is merely in the region of 2 MHz. With a blue filter at the receiver to remove the slow yellow components it, however, is possible to achieve data rates in the region of 1 Gbps with these devices. More advanced red, green and blue (RGB) LEDs enable data rates up to 5 Gbps as white light is produced by mixing the base colors instead of using a color converting chemical. Record transmission speeds with a single micro LED of 8 Gbps have been demonstrated [5], and it was shown that 100 Gbps are feasible with laser-based lighting [6].

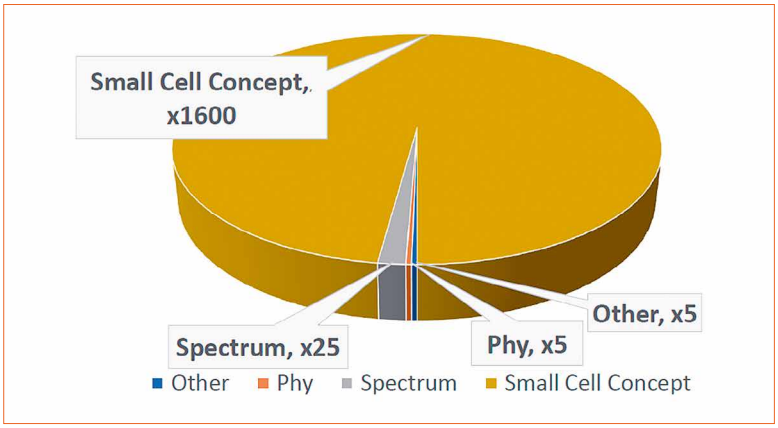


Figure 1: The main contributors to the factor 1,000,000 improvement of data rates in cellular communications: Small cell concept, followed by the allocation of new spectrum. Interestingly, new physical layer technologies have only contributed by an overall factor of 5

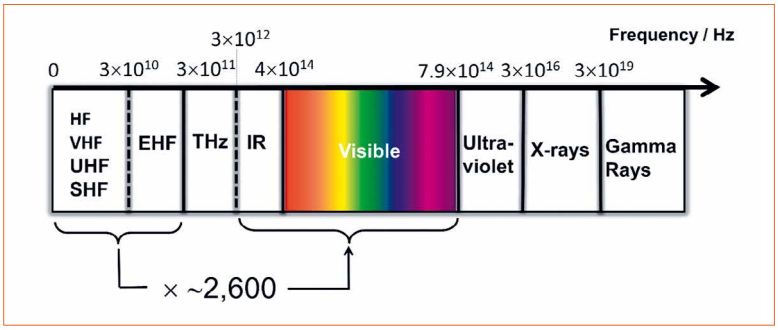


Figure 2: The radio frequency (RF) spectrum is only a fraction of the entire electromagnetic spectrum. The visible light spectrum and the infrared (IR) spectrum are unregulated, and offer 780 THz of bandwidth

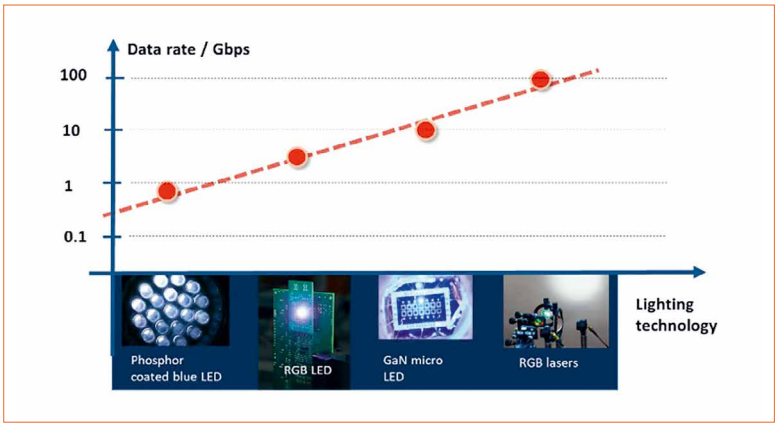


Figure 3: The maximum achievable data rates in LiFi depend on the technology of the actual light sources. Here we consider single blue-chip technology with phosphorous coating; red, green and blue (RGB) LEDs; Gallium Nitride (GaN) micro LEDs and laser-based lighting

The key advantages of a LiFi wireless networking layer are:

- Three orders of magnitude enhanced data densities [7]
- Unique properties to enhance physical layer security [8]
- Use in intrinsically safe environments such as petrochemical plants and oil platforms where RF is often banned;
- With the advent of power-over-ethernet (PoE) and its use in lighting, there exists the opportunity to piggy-back on existing data network infrastructures for the required backhaul connections between the light sources with its integrated LiFi modem, and the Internet

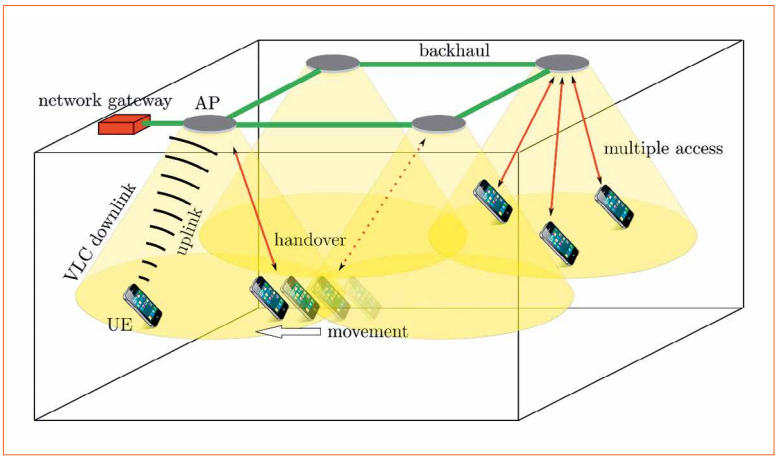


Figure 4:
LiFi attocell networking supports mobile terminals; bi-directional communication links; multiple mobile or fixed terminals connected to a single luminaire as well as a high speed backhaul

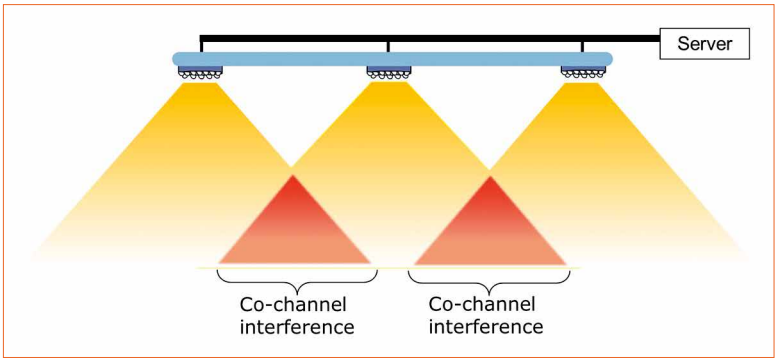


Figure 5:
CCI occurs in the region where the same light spectrum of neighboring APs overlaps, and when these APs use the same modulation bandwidth for data encoding

LiFi Networking

Figure 4 illustrates the concept of a LiFi attocell networking. The room is lit by several light fixtures. Each light is driven by a LiFi modem or a LiFi chip and, therefore, also serves as an optical base station or access point (AP). The optical base stations are connected to the core network by high speed backhaul connections. The light fixtures also have an integrated infrared detector to receive signals from the terminals. The high frequency flickers resulting from Mbps and Gbps data encoding are much higher than the refresh rate of a computer monitor, and hence these flickers are not visible to the occupants of the room. Power and data can be provided to each light fixture using a number of different techniques, including PoE and power power-line communication (PLC) [9, 10].
An optical uplink is implemented by using a transmitter on the user equipment (UE), often using an IR source (so it is invisible to the user). Each of these light fixtures, which at the same time act as wireless LiFi APs, create an extremely small cell, an optical attocell [11]. Because light is spatially confined, it is possible in LiFi to take the 'small cell concept' to a new level by creating ultra-small cells with radii less than 5 m while exploiting the huge additional unlicensed spectrum in the optical domain. The balance of light fixtures that contain APs and those that provide only illumination is determined by the requirement of the network, but potentially all light fixtures can contain APs. Compared to a single AP wireless hot-spot system, such cellular systems can cover a much larger area and allow multiple UEs to be connected simultaneously [12].
In cellular networks, dense spatial reuse of the wireless transmission resources is used to achieve very high data density - bits per second per square meter (bps/m^2). Consequently, the links using the same channel in adjacent cells interfere with each other, which is known as co-channel interference (CCI) [13]. Figure illustrates CCI in an optical attocell network.

The move from point to point links to full wireless networks based on light, poses several challenges. Within each cell, there can be several users and therefore multiple access schemes are required.
The provision of an uplink can also require a different approach from the downlink. This is because low energy consumption is required in the portable device, and an uplink visible light source on the device is likely to be distracting to the user. Therefore, the use of the infrared spectrum seems most appropriate for the uplink. In addition, modulation techniques for a high-speed uplink have to be spectrum efficient and power efficient at the same time.
Two recently developed modulation techniques that achieve this are enhanced unipolar OFDM (eU OFDM) [14], or spectral and energy efficient (SEE OFDM) [15].

Interference mitigation techniques are required to ensure within the region of strong CCI, a mobile station can also achieve high SINR, and this is a non-trivial problem which involves signal processing such as successive interference cancellation [23]. Alternative CCI mitigation techniques [16] include the use of intelligent resource schedulers. The main tasks of the 'resource scheduler' are to adaptively allocate signal power, frequency, time and wavelength resources. Typically, there are trade-offs between signaling overhead, computational complexity, user data rates, aggregate data rates and user fairness, and the optimum selection of respective CCI mitigation and resource scheduling techniques depend on actual use cases and system constraints [18][19].
Other functions of the central controller include achieving multi-user, and the handover process from cell to cell when terminals move. Handover plays an important role in LiFi networks. For example, the handover controller has to ensure that connectivity is maintained when users leave a room, or the premises. Therefore, there might be situations when there is no LiFi coverage. In these scenarios, to avoid loss of connectivity, we utilize the fact that LiFi is complementary to RF networks. To this end, there have

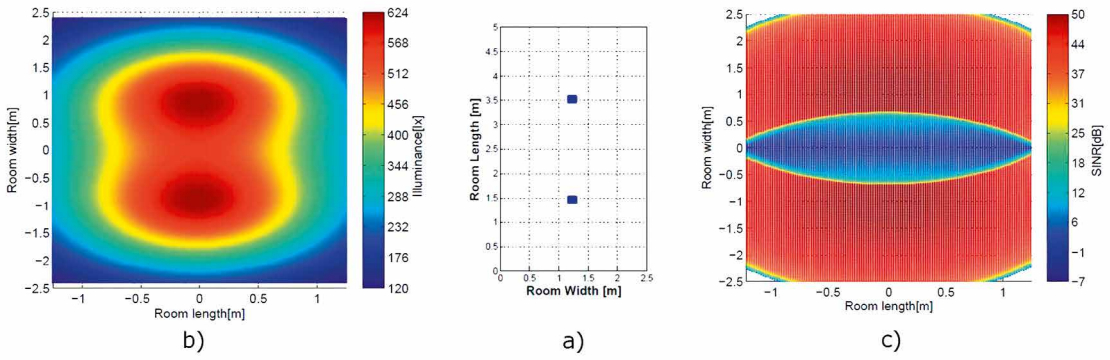


Figure 6:
A room with a size of 2.5x5 m is equipped with two LiFi luminaires installed at 3 m height pointing vertically downwards. The LiFi luminaires are illustrated by two blue squares in subplot (a). Both luminaires use the same visible light spectrum to transmit independent information. Vertically upwards pointing receivers at 0.75 m desk height are assumed. The illuminance at desk height is illustrated in subplot (b).
The resulting SINR assuming a receiver FoV of 45° is depicted in subplot (c)

been studies on hybrid LiFi/RF networks leading to three key-findings.

The three key findings on hybrid LiFi/RF networks studies:

- LiFi networks will significantly improve services quality to mobile users
- Service delivery can be uninterrupted, and
- WiFi networks significantly benefit from LiFi networks. The latter is because well-designed load balancing will ensure that WiFi networks suffer less from inefficient traffic overheads caused by constant re-transmissions which happen when two or multiple terminals are in contention [20]

LiFi attocell networks have many advantages over incumbent technologies. Unlike omnidirectional RF antennas radiating signals in all directions, a LED light source typically radiates optical power directionally because of the way it is constructed. Therefore, the radiation of the visible light signals is naturally confined within a limited region.
In contrast, RF mm-wave systems require complicated and expensive antenna beamforming techniques to achieve the same objective. Furthermore, LiFi attocell networks can be implemented by modifying existing lighting systems. Any LiFi attocell network can provide extra wireless capacity without interference to RF networks that may already exist. LiFi attocell networks, therefore, have the potential to augment 5G cellular systems in a cost-effective manner [21].

A unique feature of LiFi is that it combines illumination and data communication by using the same device to transmit data and to provide lighting. Figure a depicts a simple room scenario with two lights. Figure b shows the resulting illuminance at desk level of 0.75 m. In the particular example, the lights are placed such that within the plane at desk height, 90% of the area achieves an illuminance of 400 lux based on a given illumination requirement.
Figure c depicts the resulting signal-to-interference-plus-noise ratio (SINR). The region where the light cones overlap is subject to strong CCI, and the SINR drops significantly. It is interesting to note that the SINR can vary by about 30 dB within a few centimeters. This example also highlights that the peak SINR can be in region of 50 dB which is two to three orders of magnitude higher than the peak SINR in RF based wireless systems. The achievable data rate strongly depends on the location of the receiver and also on the field of view (FoV) of the receiver [22].
It should be noted that two lights in neighboring rooms which are separated by an opaque wall will cause no mutual CCI. This is fundamentally different from RF networks where radio signals propagate through walls and cause co-channel interference within a wide area. Because of this property of RF communications, it is difficult to achieve very high data densities.

The feature that light does not propagate through opaque objects can also be used to enhance data security (Figure 7). Our latest research has shown that physical layer security can be enhanced by a factor of 20 compared to existing WiFi.

LiFi Misconceptions

In the following we'll especially discuss five misconceptions about LiFi.

LiFi is an LoS technology

This perhaps is the greatest misconception. By using an orthogonal frequency division multiplexing (OFDM)-type intensity modulation (IM)/direct detection (DD) modulation scheme [24], the data rate scales with the achieved signal-to-noise-ratio (SNR).
This means higher order digital modulation schemes can be used in conjunction with OFDM to harness

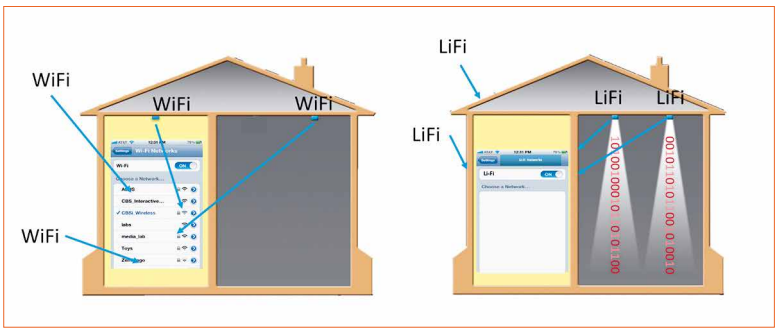


Figure 7:
Light signals are blocked by walls. This feature significantly enhances security in LiFi networks compared with WiFi networks. In a room with no WiFi router installed (left picture) it is possible to receive WiFi signals from outside the room. In contrast, in a room with opaque walls it is not possible to receive LiFi signals from outside the room (right picture). Likewise, signals from inside the room do not penetrate to neighboring rooms which are separated by walls

Figure 8:
This illustration shows the operation of a LiFi link under strict non-line-of-sight (LoS) conditions (Credits: pureLiFi)

the available channel capacity. By using adaptive modulation and coding (AMC) it is possible to transmit data at SNRs as low as -6 dB due to the use of forward error correction (FEC) coding. Figure 8 illustrates a video transmission to the laptop in the front over a distance of about 3 m where the LED light fixture is pointing against a white wall in the opposite direction to the location of the receiver. Therefore, there is no direct LoS component reaching the receiver at the front, but the video is successfully received. Obviously, if the wall would be dark, more light would be absorbed which would compromise the SNR at the receiver. If the SNR drops below the -6 dB threshold, an error-free communication link would not be possible. However, in low-light conditions single photon avalanche diodes may be used at the receiver which enhance the receiver sensitivity by at least an order of magnitude [26].

LiFi does not work in sunlight conditions

Sunlight constitutes a constant interfering signal outside the bandwidth used for data modulation. LiFi operates at frequencies typically greater than 1 MHz. Therefore, constant sunlight can be removed using electrical filters. An additional effect of sunlight is enhanced shot noise, which cannot easily be eliminated by electrical filters. In a study [27] the impact of shot noise was investigated qualitatively, and it was found that data rate is compromised by about 5%. Saturation can be avoided by using automatic gain control algorithms in combination with optical filters. In fact, we argue that sunlight is hugely beneficial as it enables solar cell based LiFi receivers where the solar cell acts as data receiver device, and at the same time harvests sunlight as energy [28].

Lights cannot be dimmed

There are advanced modulation techniques such as eU-OFDM [14] which enable the operation of LiFi close to the turn-on voltage (ToV) of the LED which means that the lights can be operated at very low light output levels while maintaining high data rates.

The lights flicker

The lowest frequency at which the lights are modulated is in the region of 1 MHz. The refresh rate of a computer screen is about 100 Hz. This means the flicker-rate of a LiFi light bulb is 10,000 higher than that of a computer screen. Therefore, there is no perceived flicker.

This is for downlink only

A key advantage is that LiFi can be combined with LED illumination. This, however, does not mean that both functions always have to be used together. Both functions can easily be separated (see the comment on dimming). As a result, LiFi can also be very effectively used for uplink communication where lighting is not required. The infrared spectrum, therefore, lends itself perfectly for the uplink. We have conducted an experiment where we sent data at a speed of 1.1 Gbps over a distance of 10 m with an LED of only 4.5 mW optical output power.

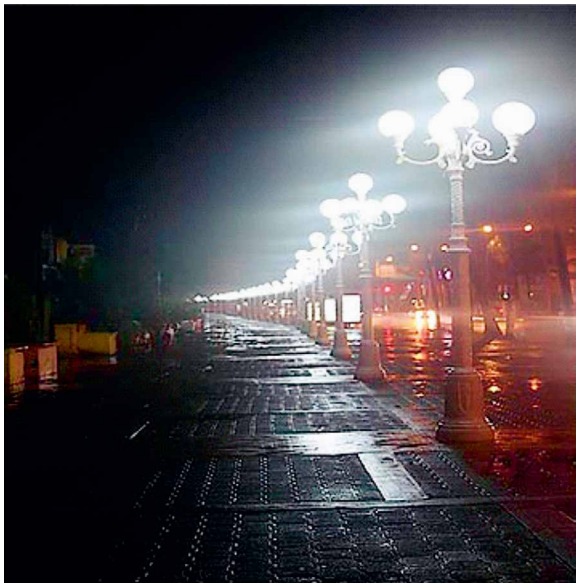


Figure 9 (left):
Streetlights could form the backbone of future 5G networks in cities

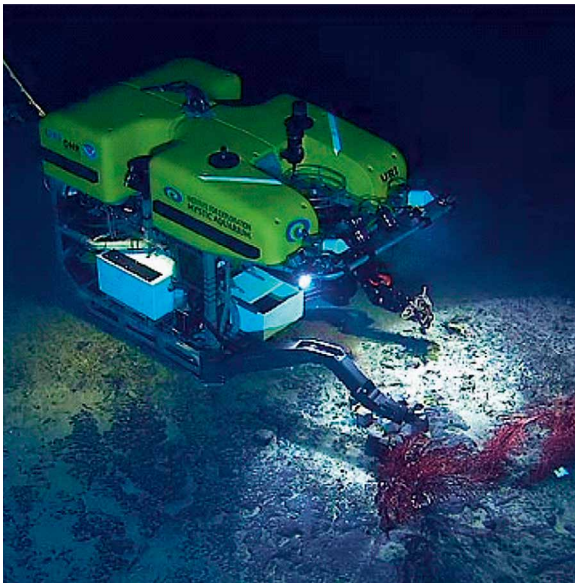
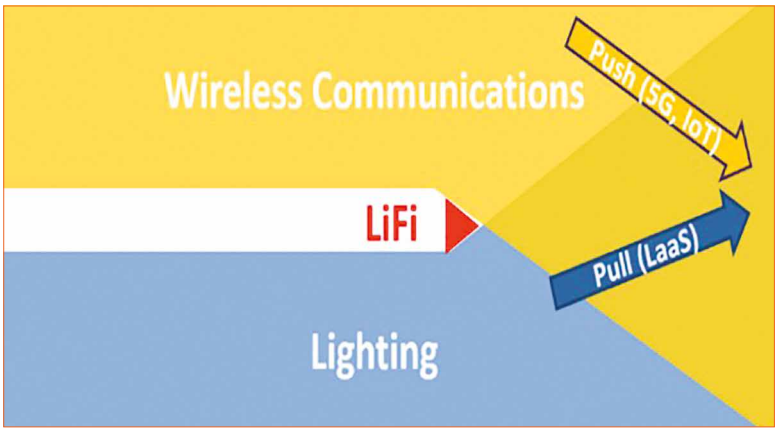


Figure 10 (right):
LiFi will work underwater, and the lights that are used for illumination in remote operated vehicle and underwater drones can be used to exchange information among these autonomous underwater machines. It will be possible to create mesh networks to send information over long distances under water to create sensor networks for environmental monitoring

LiFi Applications

LiFi applications are manifold. As shown in figure, streetlights could play a major role in future smart cities. They could provide gigabit bi-directional wireless connectivity. Interestingly, with LiFi this would also be possible during daytime. As illustrated in figure, LiFi can also unlock smart transport systems which are part of our fully connected smart cities. Because cars typically use LEDs or lasers in headlights and taillights, these lights can be used for gigabit inter-car communication, and data communication to street furniture such as traffic lights and street lights.

Unlike RF communication systems, LiFi will also work underwater as shown in figure. This will allow new ways to connect remote operated vehicles, and it also will allow divers to communicate with each other. This will enhance safety in difficult underwater missions. Transmission distances of up to 100 m have been demonstrated. New detector technology such as single photon avalanche detectors (SPADs) are currently being investigated to achieve much higher distances.



An additional important application area is the internet of things (IoT). The IoT can be classified in the industrial IoT, and the general IoT. The latter may connect our future appliances such as our toaster, microwaves, freezers, ovens and fridges to the internet. In fact, LiFi will enable the LED status lights of these home appliances to connect them to the Internet via the domestic lighting system. This connectivity will act as the 'nervous system' for our future things. Assume embedded microprocessors, sensor, memory and machine learning algorithms, LiFi will provide the high bandwidth, low latency connectivity to realize meaningful artificial intelligence. For example, by using predictive maintenance it will be possible to establish if an item is liable to break in the near future. The item could then order itself or as specified by the user (before it breaks) from the Internet automatically, avoiding inconvenient disruptions, and saving us time. Another important application of LiFi is indoor positioning and navigation. Typically, there are many lights in an indoor environment. Light is confined to a small area. This feature can be exploited to readily establish the position of people and assets within a few meters.

Market Disruption Potential

LiFi is a disruptive technology that is poised to impact a large number of industries. LiFi is a fundamental 5G technology. It can unlock the IoT, drive Industry 4.0 applications, light-as-a-service (LaaS) in the lighting industry, enable new intelligent transport systems, enhance road safety when there are more and more driver-less cars, create new cyber-secure wireless networks, enable new ways of health monitoring in aging societies, offer new solutions to close the digital divide and enable very high-speed wireless connectivity in future datacenters.

LiFi will have a catalytic effect for the merger of two major industries:

- The wireless communications industry and
- The lighting industry as illustrated in figure 12

Figure 12 demonstrates the vision of how LiFi could lead to a merger of the wireless communications industry and the lighting industry. In the lighting industry, LiFi provides

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a means to diversify and to develop new applications and this will propel the trend of light-as-a-service (LaaS). This will pull the lighting industry into the markets of the wireless communications industry. As a result, new business models will be created in the lighting industry which are needed as the life-time of an LED light bulb is 20 years and more. The wireless communication industry requires unprecedented data rates and orders of magnitude higher data densities due to new services in 5G such as augment reality and virtual reality as well as mobile TV.
In addition, wireless networks will need to connect billions of internet-of-things (IoT) devices. This will accelerate the radio frequency spectrum crunch, and 'LiFi' will act as a 'pressure valve' which means that there will be a market 'push' to develop wireless communications equipment based on light, a market that has classically been served by the lighting industry

In 25 years from now, we moot that the LED lightbulb will serve thousands of applications and will be an integral part of the emerging smart cities, smart homes and the IoT. LaaS will be a dominating theme in the lighting industry, which will drive the required new business models when LED lamps last 20 years or more. LaaS in combination with LiFi will, therefore, provide a business model driven 'pull' for the lighting industry to enter what has traditionally been a wireless communications market. In the wireless industry, LiFi has the potential to create a paradigm shift by moving from cm-wave communication to nm-wave communication. It is, therefore, conceivable that the wireless industry and the lighting industry will merge into one. An important prerequisite for the large-scale adoption of LiFi technology is the availability of standards. In this context, efforts have started in IEEE 802.15.7, IEEE 802.11 as well as ITU-R to standardize LiFi technology. Notably, there is now a Task Group on Light Communication within 802.11bb.

Conclusion

The visible light spectrum and infrared spectrum together, offer 2600 times more bandwidth than the entire RF spectrum. LiFi harnesses the abundance of bandwidth to achieve new wireless networks which augment existing RF-based wireless networks. These networks increasingly suffer from bandwidth shortages. With current commercially available optical devices it is possible to achieve multi-gigabit bi-directional data links. LiFi integrates these links into a full wireless network which is augmented with functions such as multiuser access, handover and CCI mitigation. This paper has attempted to clarify a number of misconceptions about LiFi. A few selected use cases have been discussed. It has been shown that LiFi has the potential to lead to a merger of the lighting and the wireless communication industries. Therefore, LiFi has become a reality and this technology is here to stay for a long time. ■

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AI & Lighting

Recently, Artificial Intelligence has emerged as an evolutionary force in almost every industry, demonstrating its potential to radically change existing processes. In common literature, AI is interchangeably used with Machine Learning for which various tools have already become commonplace. Henri Juslén, D.Sc (tech.), Chief Future Illuminator, Omar Nasir, M.Sc (tech.), Data Scientist, and Javad Nouri, M.Sc, Data Scientist at Helvar Oy Ab discuss AI on the context of the lighting industry where the scope of applications of AI is similarly quite broad, impacting the various stages involved in the lighting life-cycle such as design, installation, commissioning and configuration.

The lighting industry commonly employs novel techniques in lighting design and control. Major transformative changes within the industry include the evolution of the light bulb and the introduction of inter-networked lighting components that implement protocols such as DALI. Recently, Artificial Intelligence has emerged as an evolutionary force in almost every industry, demonstrating its potential to radically change existing processes. In common literature, AI is often interchangeably used with Machine Learning for which various tools have already become commonplace. In the context of the Lighting Industry, the scope for applying AI is intriguingly broad, impacting the various stages involved in the lighting life-cycle such as design, installation, commissioning and configuration. For example, a self-learning network of lighting components can communicate and set up itself without requiring human intervention similar to auto commissioning systems used in the IT industry. This will decrease the time needed to commission new lighting installations. By observing and measuring indoor environments, an AI based lighting system can optimize and tune light parameters accordingly to impact user experience and well-being.

The utility of such a system is not limited to end users or tenants but extends to other stakeholders, such as building owners and facility managers as well. A data-driven network of lighting components continuously generates data which is collected and stored at a centralized server. AI algorithms can be designed to run at the source component, such as a sensor, for decentralized, real-time decisions, or at a server for making centralized decisions. Furthermore, the collected data can be utilized for other Building Management Systems (BMS) such as Heating, Ventilation and Air Conditioning (HVAC), or access management. However, the technology is not without its caveats. Cameras augmented with AI can detect precise occupancy and movements in a room or space, but the visual feed would require strict adherence to privacy laws. Another significant challenge is the limited human understanding of AI, which impedes its speed of adoption as well. In summary, paying attention to privacy, there are a lot of opportunities for applying AI within the lighting industry with significant impact to improved user experience, comfort, productivity and ultimately profitability.

Introduction

Artificial intelligence (AI) refers to the study of systems artificially built by humans that can interpret the environment they are exposed to, make inferences and take actions to maximize their successes for some pre-defined objectives.

The logic of making such decisions can be either explicitly programmed, or automatically learnt from the environment. The former is generally referred to as "rule-based" systems. An example of such a system are the so-called expert systems which operate in a specific domain. The rules of such systems are created and tuned by human experts in the domain. Expert systems for diagnosing diseases is an example of such a system which helps doctors diagnose medical conditions given the symptoms received from the patients.

Machine learning is a subdivision of Artificial Intelligence and studies the ability of systems to learn, to find patterns and to make decisions based on the data they receive from their environment without explicitly being programmed. For example, machine learning can be used to predict the chance of events happening in the future, or automatically find which items in a department store are more likely to be bought.

Figure 1 shows an Artificial Neural Network (ANNs), which are machine

learning systems inspired by biological neurons. In such systems, units known as neurons work together. Every neuron receives a signal either from the environment or from other neurons and produces an output signal based on the input. Outputs of neurons can, in turn, be passed on to other neurons as input signals or can be used directly to take actions. When these networks of neurons are exposed to enough data and see the results of actions, they adapt and learn how to adjust their input so that their output results in the best outcome for the task at hand. This phase is known as training the network.

Neural networks are organized into layers, so that output of one layer becomes the input to the next layer. The number of these layers is referred to as the "depth" of the network. Generally, the ability of a network to learn from the data it is exposed to improves with the increase in its depth, which translates to improved performance for the task at hand. Deeper network, however, means more resources are needed for training the network. Artificial Neural Networks have been around since the 1940s, however, a limiting factor at the time was the computational intensity of the algorithms to train the networks.

Recently, with the advance of general-purpose computing on Graphical Processing Units (GPU) and with more data available for training the networks, deep neural networks can be trained and used more efficiently, and deep learning has been more widely known and used in the industry for real-world problems.

Although Artificial Intelligence, Machine learning, Artificial Neural Networks, and deep learning are sometimes used interchangeably it is worth distinguishing them and knowing the differences between them. Figure 2 demonstrates the relationship between these concepts in a Venn diagram.

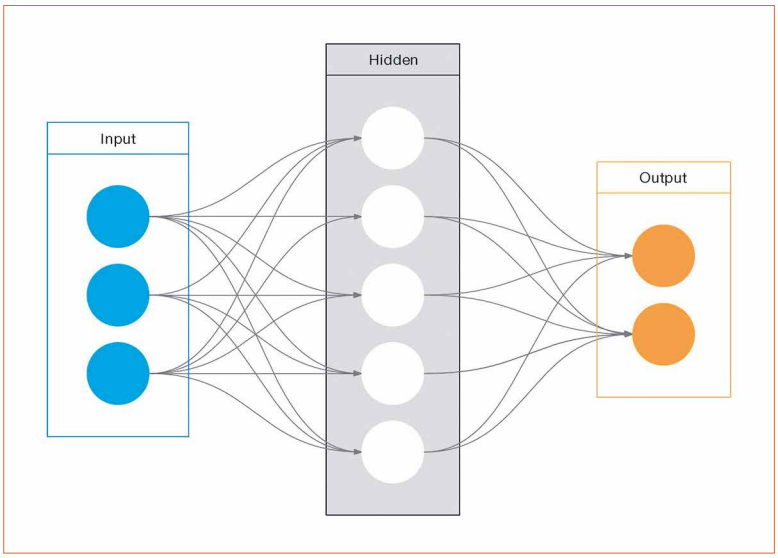

Figure 1:
Artificial neural network with interconnected layers of neurons [1]

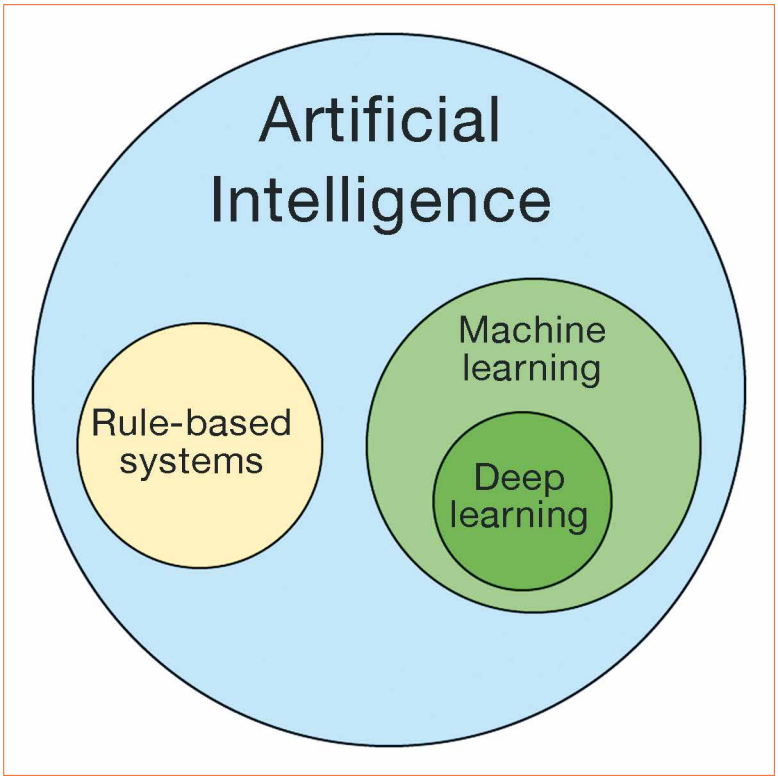

Figure 2:
Artificial intelligence vs. machine learning

Machine learning problems fall into two categories: supervised and unsupervised learning.

Supervised learning involves exposing the system to input data and its corresponding output values, whereby it learns to predict the output from the input data.
An example is predicting the house prices using features such as size, neighborhood, etc. The system uses historical data on house prices and the relationship between the features of the house and the price and learns to predict the price in the future.

On the other hand, in unsupervised tasks, we do not generally know the ground truth, but we are still willing to find patterns and regularities in the data. A classic example of unsupervised machine learning task is the problem of automatic grouping of objects so that similar objects fall in the same cluster.

Supervised tasks, in turn, can be separated into Classification and Regression problems. In Regression, the output is a continuous number, such as house prices. The classification problem is defined by the ability of a system to predict the category or

class of the input data. For example, predicting if the weather tomorrow is going to be sunny, cloudy, rainy, etc.

Tools

Many industries started using AI and Machine Learning long ago to deliver value. Consequently, a great deal of infrastructure and tools have been created and are at the disposal of industries that are adopting data-driven approaches in their business strategies. Hardware and software infrastructure are available and widely used in Internet of Things (IoT) for collecting data from devices in the building as well as cloud infrastructure for storing, analyzing and delivering final products from the collected data.

Cloud providers such as Amazon Web Service (AWS), Google Cloud Platform (GCP), and Microsoft Azure have the tools needed for collecting and storing the data. These cloud providers even have their own solutions for IoT tasks, such as AWS IoT, GCP IoT Core, and Azure IoT Hub.

From a software tools point of view, implementations of state-of-the-art machine learning algorithms are available and readily usable in high level languages, such as pandas and scikit-learn for data analysis and machine learning in Python, Tensorflow, PyTorch, and Microsoft Cognitive Toolkit (CNTK) for deep neural networks, etc.

This wide selection of tools and infrastructures makes it easier for new industries to adopt AI, since they do not need to start from scratch. The only thing needed is to create the pipeline for collecting the data, using available tools and to start building solutions by processing the data.

Possibilities of AI in Lighting

In general, present lighting control systems are built on the belief that we know what will happen now and, in the future, i.e. somewhere there is a mastermind (the specifier or designer) who is able to develop rules governing how lighting should work in different situations. The cruel reality is that there is no such person in any professional lighting project. The problem has been solved so far by re-commissioning or re-configuration, for which an expert is needed. Lighting systems are getting more flexible, which might mean that they are also becoming more complex to setup and require special knowledge and more resources. We therefore deal with both supervised and unsupervised machine learning problems in the lighting industry, expanding to all stages of lighting life cycle, from design to commissioning to end-user experience.

Quite often, end users either do not notice or do not understand that lighting could and should work better. This means that an expert is invited only when the problem is severe (e.g. the lights will not turn on or the lights are flickering). An expert would then have to monitor lighting, space, users and their tasks over a longer period of time to be able to ensure the optimal lighting solution at all times. Unfortunately, this is not affordable nor practical in most situations.

AI for designers

Self-learning algorithms, i.e. continuous auto-commissioning through machine learning have the potential to serve as an "expert on-site" and to help grow the adoption of controllable lighting. From the designers' point of view, this means fewer compromises. Lighting can be designed without huge tolerances, like in fade times of the systems. Future AI solutions could also help to make lighting design faster and more successful. For example, if the users of commonly used Lighting design software would store their data to a cloud database, it could then already be used to provide improved recommendations at the beginning of the project. Obviously, this is one of those examples where a complementing business model is needed to ensure a successful solution.

AI for installers

Installing a lighting system takes time, which depends on the quality of planning, building structures, lighting application, knowledge and experience of personnel, and so on. Time is equally valuable for installers as well. In the future, advanced digital twins, building information models and augmented reality supported by AI could speed up installation and decrease errors. Interestingly, a significant amount of time in the building industry is wasted due to ineffective coordination, whereas the objective is to equip the right team of technicians with the correct tools and materials at the required place and time. Solving these issues might prove to be a sweet spot for AI. However, at the moment AI can only offer indirect benefits, which are monetized more in the commissioning and configuration phase.

AI for commissioning & configuration

Helvar's ActiveAhead® solution is an example of AI being used for automatic commissioning of lights. Luminaires communicate with each other about their current light stage and learn sequential patterns in the occupancy around them. This way, they can predict the occupancy in their area using the information they get from other luminaires, thus illuminate the area even if the user is at the very edge of the lighting area. This reduces the amount of effort for commissioning and programming the lighting control, and in case there is any restructuring in the layout of the area, recommissioning is not necessary since the lights will learn and adapt to the new patterns. This example highlights the future opportunities in using AI to help commissioning and configuration, well. Using the available data, it is possible to make this part of the process easier or even fully

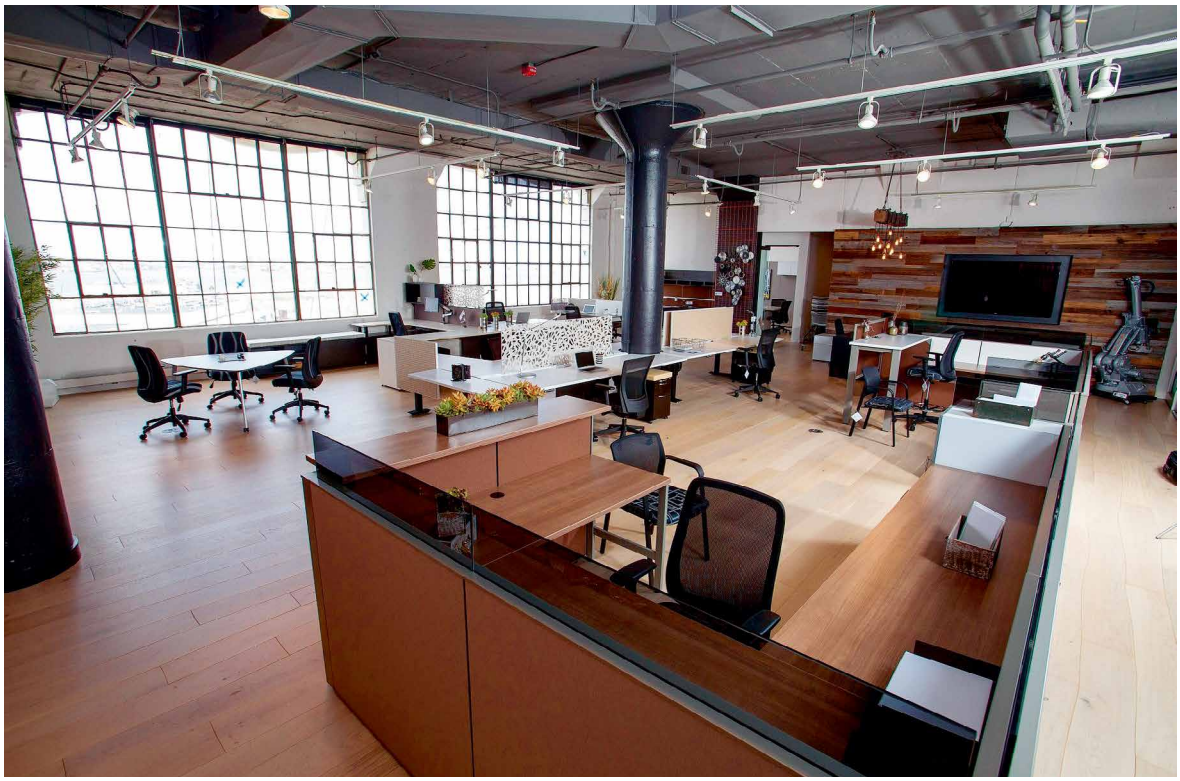

Figure 3:
Active lighting in empty spaces [2]

automated. When adding more advanced sensors and cloud level processing power in the future, auto-configuration and especially continuous configuration might be the mainstream of lighting in larger buildings.

AI for end users (tenants)

The reason to design, install, commission, configure, maintain and control lighting is to make the space usable for users. Good results can be achieved without any AI, if environment and needs are not changing, by making sure that selected solutions are providing illumination well above lighting norms. Unfortunately, as the needs do often change, users of the space develop different requirements. One way to solve this is to have user interfaces that allow users to change conditions. This often leads to non-optimized conditions as users/people either don't use available user interface or ignore personal user interfaces (after an initial phase of trying them out). It has been seen that people tolerate quite bad lighting before starting to control it. Hence, control should not be left just to the users. AI can play a role here. One option is supervised learning, where the system can learn the user preferences by recording their selections. It is also possible to collect data from multiple sources and offer automatic lighting that fits user needs and make lighting recommendations.

AI for building owners and facility management

Building owners who are not tenants themselves can be incentivized by improving the profitability of their buildings. Tenants who are willing to pay substantial rents will demand that the building should be managed properly. Maintenance of technical systems is an evident use case of AI. It is already possible not only to see what the problem is and where it is, but also to predict the malfunction of a component in a system. This can be done by analyzing historical data and predicting future events. Figure 3 shows an environment where the lighting remains turned on even if there are no occupants in the space. This leads to excessive energy consumption. By combining the data of multiple sensors, fade times can be tuned according to real needs. These are examples, where maintenance and the operating cost of a building can be lower while improving the tenant's comfort in a space. The value proposition AI has to offer to building owners is the improvement in overall tenant satisfaction, which inevitably translates to greater profitability through improved rental contracts.

Architecture of Intelligence

Designing the architecture of a network that supports AI based decision making requires special considerations. The first step is to create a pipeline for data collection, which enables the data generating devices to connect to a server. This server is responsible for communicating with the cloud. It can be hosted either locally, in the premises of the building, or in the cloud. The most important attributes of this network are reliability, flexibility and scalability. The network must be able to continuously send data, whilst catering to any changes in its topology either in the form of rearrangement or the addition of devices.

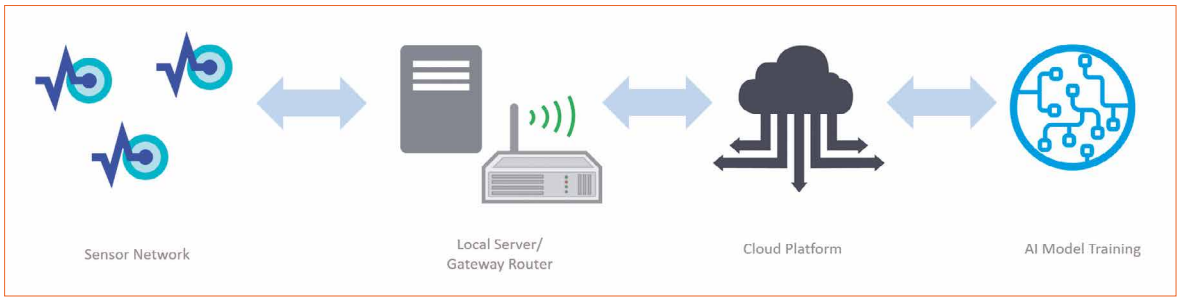

Figure 4:
Example architecture for building AI products

The next step is to collect sufficient data in the cloud and train the AI model on the dataset. The trained model can be deployed in the network using its components to host the algorithm, which should preferably be the local server or router. The advantages to this approach are availability in case of connection failure to the cloud. However, this requires the edge devices to have higher computational power, which constrains the capability of the model. The alternative is to run the model in the cloud. This allows for greater model complexity at the cost of increased communication with the device network.

Finally, the output from the trained model can be used for making decisions regarding lighting control systems. For example, the algorithm can instruct a device to turn off the lights based on the output from the AI model.

Beyond Lighting Control

Modern lighting control systems incorporate an array of sensors, including motion and thermal devices. These sensors generate data based on interactions with their users. For example, an occupant in a room will generate motion events and have a specific heat signature. Similarly, the system can also use electricity meters to determine the energy consumption of luminaires.

All these sensors measure a specific parameter, which is interpreted in the context of lighting control to make informed decisions. However, there exists an opportunity to expand the interpretation beyond lighting control systems. For example, an increase in the heat signature can indicate an increase in the number of people in a room. Similarly, variations in energy consumption patterns can provide insights into how a particular space is being utilized. These interpretations are useful as they establish a framework which allows integration of AI based lighting networks with external systems.

To put the above discussion in perspective, consider a heating and ventilation system otherwise commonly known as HVAC. If the AI is able to model the number of occupants in a room based on information from thermal and motion sensors, it can instruct the HVAC to change the air quality to improve user well-being, even in advance considering the impact delay of HVAC systems to spaces. The same information can be used to identify which rooms are more frequently used, and therefore, provide insights to a building owner on the possibility of rearranging the floor layout. By improving space utilization, a building owner can maximize profitability by renting out underused spaces. Finally, it is also possible to optimize electricity costs by analyzing energy readings from different luminaires and the pattern of people flow in different rooms.

Challenges

There are various challenges related to the adoption of Artificial Intelligence in different industries. The following sections briefly describe some of these challenges.

Human challenge

Artificial Intelligence is deeply rooted in mathematics and computer science. Recent developments related to computational and algorithmic efficiency have lowered the barriers to entry, but the overall research output is still constrained to a niche group of scientists. Therefore, it is challenging to correctly interpret the decision capability of an AI algorithm for people unfamiliar with the inner workings of the algorithm. Moreover, the concept of machine intelligence has been romanticized by the entertainment industry to the point that the general population is highly skeptical of its benefits. As a result, the most commonly cited threat vis-à-vis AI is the eventual replacement of human labor. In practice, AI is being used as a supplementary mechanism to automate banal tasks and improve decision making for user well-being. This disconnect between the interpreted and the intended purpose reduces the willingness to adopt the technology at a wider scale.

Data challenge

The first and foremost requirement of building robust AI based solutions is the availability and quality of data. The decision to incorporate such products in an existing portfolio is usually taken based on an initial analysis of available data. However, the quality of analysis is closely linked to the interpretability of data. For example, imprecisions in an audio recording device can increase accumulated noise in the output, which will reduce the effectiveness of any subsequent analysis. Similarly, data generation methodologies can be constrained by network capacity, and instead attempt to summarize the observations made by the devices. AI algorithms modelled on such abstractions will produce generalized results which might not be suitable for applications that require

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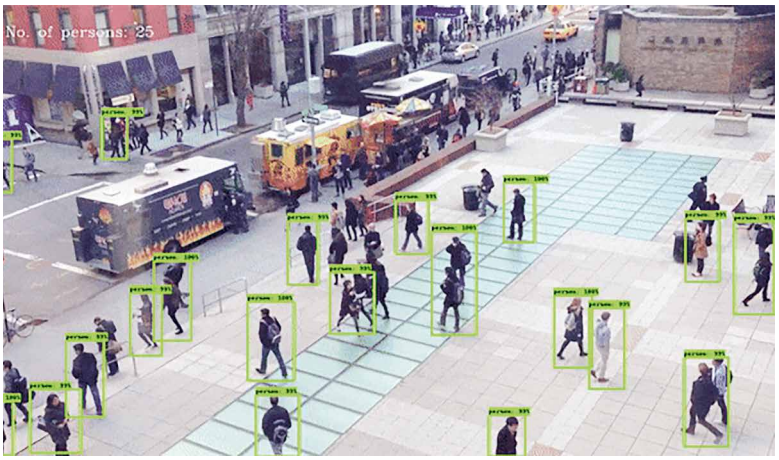

Figure 5:
Public crowd counting systems [3]

fine-grained control. Therefore, AI practitioners must understand the limitations of the available data, otherwise the algorithm will model imperfections in the data and will likely add reduced value to the customer.

The heightened interest in AI has had a significant impact on how companies build their future strategies. Many companies have existing software infrastructure in place that does not support data generation or collection. Moreover, it is equally difficult to extract data from legacy systems that have not been designed for this purpose. Investment in modification and upgradation of legacy systems is therefore needed to enable reliable data collection. This can impede execution of company strategies that are being developed around AI driven products. However, nascent organizations an hire consultants and data engineers when building the initial infrastructure to ensure seamless integration with AI driven products in the future.

Privacy challenge

Lastly, it is vital to talk about ethical data collection and usage. Any AI based solution that optimizes user experience will incorporate user data to a certain extent. It is important that the collected data does not violate the privacy of any individual. For example, a common application of AI is to segregate similar user profiles. Therefore, it should be ensured that any personal information cannot be used to identify individuals, but rather, the information is obfuscated before feeding it to a data analysis algorithm. There are privacy laws to ensure data misuse does not take place, but it can vary from region to region. In Europe, for example, GDPR ensures compliance with ethical data standards for any company working with user data.

The most typical example of a data privacy issue arises when using cameras to collect data. A visual feed can provide very accurate readings, such as traffic flow or the number of people in an area as shown in Figure 5. However, it also allows facial recognition making this format of data susceptible to misuse as well. Aspiring companies must consider ethical issues when specifically dealing with these data collection methods.

Conclusion

Disruptive technologies have traditionally faced various challenges and obstacles in their wide spread adoption and acceptance, as is the case with Artificial Intelligence as well. However, its benefits and transformative potential are undeniable. It has had a significant impact on industries such as e-commerce and media entertainment but has made limited inroads in more conventional economic activities such as lighting and building management. Previous sections discussed some of the improvements that can be introduced in the lighting industry and the possibility of extending their utility beyond lighting as well. It further highlights associated challenges and pitfalls that AI and Lighting practitioners should bear in mind while designing future systems. This will ensure development of disruptive but reliable solutions which can positively impact user comfort and well-being, whilst maximizing profitability for various stakeholders in the lighting industry. ■

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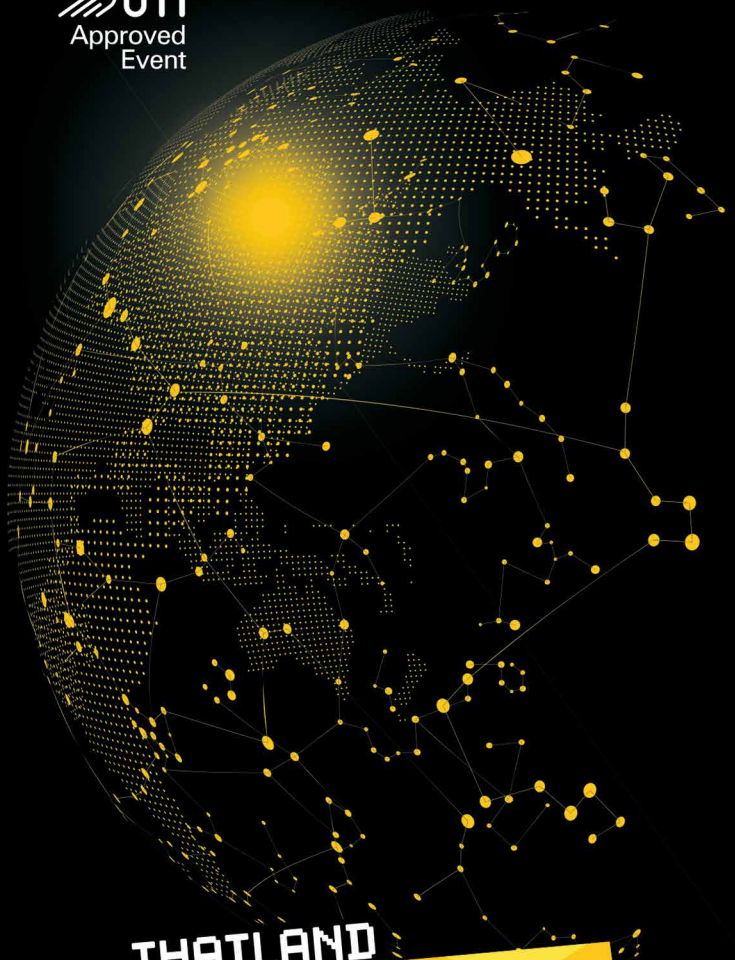

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IP Analysis of Flicker Suppression Technologies for LED Lighting

Since we have been using electric lamps "flicker" has been an important point of discussion. Especially gas discharge lamps (high pressure lamps, fluorescent lamps) driven with AC show this phenomenon. At 50 Hz the light emitting discharge switches on and off 100 times per second, which is a frequency close to the perception threshold. Most people don't really see the flicker effects but our brains often react to flicker with stress symptoms or headaches. Unfortunately, the necessary driver electronics for LEDs often cause flicker, which means that the topic is still highly relevant. Dr. Guenther Sejkora, innovation manager at Luger Research analysed the subject in respect to IP activities in the industry.

Talk about flicker quieted down when electronic ballasts became more common in the 1990's. The flicker problem was solved using high frequency technology, but when LED lighting started to become popular in the early 2000's the problem of flicker became relevant again. Low quality converters, AC-LEDs and PWM dimming at low frequencies can cause perceivable flicker of light.

Driving technologies for LED differ from those used for discharge lamps. If we want to avoid flicker with LEDs, the technologies for suppression might be different from those already known from discharge lamps. In order to give an overview on these technologies we used a commercial patent analysis tool.

The Query

To find a good question is not easy. You have to find keywords and combine them with a logical expression using "AND", "OR" and "NOT". The key challenge is to find the right words. If the query is not strong enough (e.g. you just search for "flicker") you will find too many patents (in our case patents that don't deal with avoidance of flicker). If the query is too strong (e.g. you search for "flicker AND avoid"), you will lose important patents (in our case patents, that use the term "supress" instead of "avoid").

It seems to be best to start with a weak query, select 20 patents randomly and evaluate them by reading the abstract (and if necessary also the claims). In the first step more than 10 patents out of the 20 described inventions had nothing to do with our search. We analysed these "invalid" hits to get clues on how to refine our query to exclude these patents. We proceeded the same way in several loops until we were sure that more than 80% of our hits would really correspond to our research.

In eliminating unwanted hits a reduction of IPC-(sub)classes is also helpful. We decided that the most important subclasses for our research would be H05B, H01L and F21V.

Another question is where to search for the keywords. There are three sections available for search: abstract, claims and description. The abstract section is the most important as the problem to be solved is normally described in the abstract. In some cases – especially if flicker is only a sub-topic within a comprehensive patent – we would only find the right keywords in the claims. If we find the keywords in the description only we can be quite sure that flicker suppression is not the topic of the patent.

The query we used was: "LED" AND ("avoid" OR "suppress" OR "reduce" OR "eliminate") AND ("flicker" OR "strobing" OR "stroboscopic" OR "flickering" OR "flickers") and we looked for it in the abstract and in the claims sections. The search result does not show all patents found but only one representative patent for patent families.
Our search resulted in 829 patent families that describe technical solutions for flicker suppression.

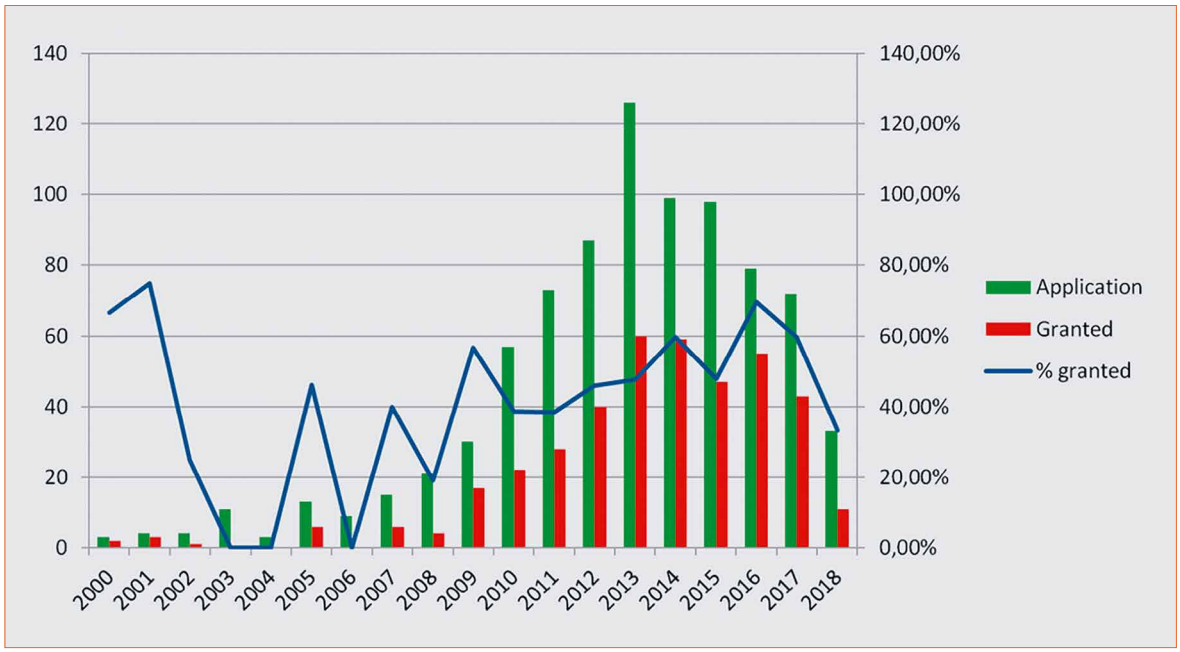

Figure 1:
The diagram shows number of patent applications and number of granted patents. For yearly application rates > 25 (since 2009) applications and granted patents are in good correlation (about 50% granted)

Figure 2:
Yearly innovation rate for "flicker suppression" - applications with predictive values until 2021. Maximum was reached in 2013

Statistical Interpretation and S-curve Analysis

The first important question is: where are we in respect to the flicker-suppression technology S-curve? So we plotted the number of applications (green bars) and the number of granted patents (red bars) over time from 2000 to 2018 (Figure 1). The blue line shows the ratio between granted patents and applications.
For small numbers of applications/year (<25) this ration varies widely due to non-representative statistical samples. For >25 applications/year the number of applications and granted patents are correlated with a ratio between 40% and 70% (which gives a mean ratio of 50%).

This is especially important for the last few years as we know for those only the number of applications but maybe some of the patents are not granted yet.

Looking at the applications only (Figure 2) we see published applications (dark green) and the prediction (light green) for not yet published applications in 2018 and for the years 2019 – 2021.
We see a small number (<15 applications/year) of applications in the years until 2007, a progressive fast increase between 2007 and 2013 with a maximum of 126 applications/year and a decay to 41 applications/year.

The technology S-curve can be derived by integrating the number of patents over time. As we already explained, the number of granted patents is correlated to the number of applications with a mean factor of about 50%, therefore we can also integrate the number of applications if we only look for the shape of the S-curve (Figure 3). The S-curve is already flattening, which means the technologies for flicker suppression in LED luminaires becomes mature. Applying already developed technologies becomes more and more common, further development of these technologies becomes less frequent.

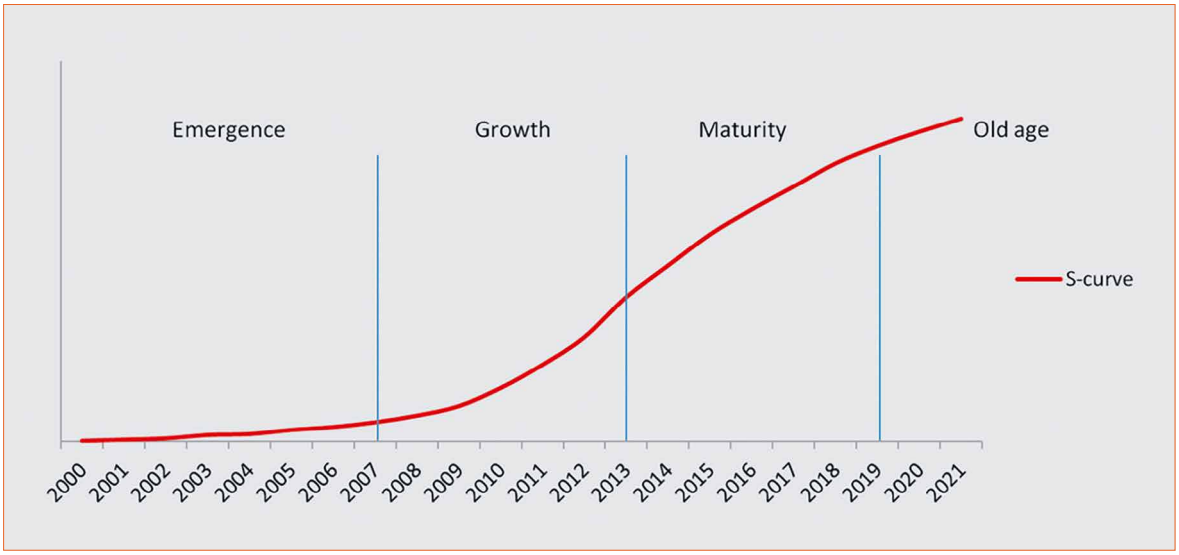

Figure 3:
Technology S-curve for "flicker suppression" derived from application rate. Maturity (inflection point) was reached in 2013. Currently the S-curve flattens, indicating that present flicker suppression technologies are becoming old (low innovation rate)

Top Applicants

To go into more detail, we analysed the top 4 applicants (number of patent families in the field of flicker suppression between 2000 and 2018).

Top 4 Applicants and Number of Patent Families:

- Sharp (Japan): 19 patent families
- Sichuan Sunfor Light (China): 19 patent families
- Seoul Semiconductor (Korea): 15 patent families
- Philips (The Netherlands): 13 patent families

Our first question was: Where are the patent activities of these companies positioned on the time axis (Figure 4). Sharp and Sichuan Sunfor Light set their main research activities mainly in the growth phase of the S-curve and ended their activities with beginning of maturity. This signifies focused research on the flicker topic for certain time and patenting the results. After this active phase both of them stopped their research activities and started exploitation (or – unlikely – left the technology area) Although both patented in the same phase of the S-curve, there is still a big difference.

Sharp started with low resources on the topic and enhanced their activities from year to year. This can be interpreted as patent activity in the course of a typical R&D project. On the contrary, Sichuan Sunfor Light started in 2010 with 11 patent applications and applied for a lot fewer patents over the next years. This pattern could have been generated by a break-through research result in 2010 and as a follow up of the coverage of the technology field.

Seoul Semiconductor and Philips acted differently. Looking at how the applications were distributed over time, we see that they are more or less evenly spread. This indicates that for these companies flicker is more or less a permanent topic. They don't deal primarily with flicker suppression, but this topic is always present in various R&D projects and leads to inventions every now and then. Philips already did their first applications in 2000, leading with one of the most cited patents regarding flicker suppression.

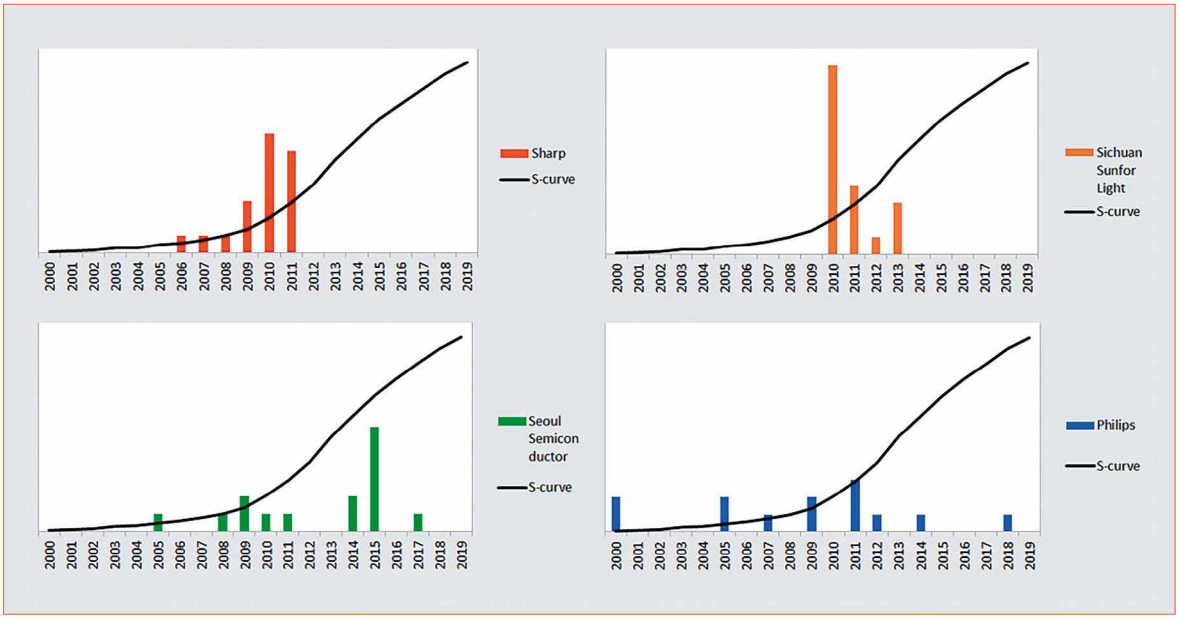

Figure 4:
Patent activities of top applicants compared to the S-curve. Sharp (top left) and Sichuan Sunfor Light (top right) show dedicated activities in the growth phase of flicker suppression technologies. Activities of Seoul Semiconductor (bottom left) and Philips (bottom right) seem to not be correlated with the S-curve

Technology Fields

Statistical evaluation doesn't help too much if we want to find out which technologies are used to supress flicker. We have to go through the patents and read (at least the abstract) to find out. Or we use a patent analysis tool that works with artificial intelligence (AI) algorithms. These algorithms try to interpret the text of an application and assign it to specific topics. As a result, on the one hand, the problem areas for which the patent offers a solution can be recognized (e.g. flicker caused by driving the LED with AC). On the other hand, technologies for solving the problem will show up (e.g. long afterglowing phosphors).

In order to find subject areas, keywords are put in context to each other. If certain combinations are found frequently enough in different applications, they are identified as related topics and the individual keywords recognized as important topics. That can, but does not always, have to be meaningful. Therefore it is important to interpret topics found with artificial intelligence using "human intelligence".

A first representation of AI results is a "Word Cloud". Topics found to be important in the analysed patents are represented by large letters, less important ones by smaller characters. All topics are grouped around each other in the shape of a cloud. Topics will not be grouped to subject areas.

Analysing all patents regarding flicker suppression results in the Word Cloud shown in figure 5. The central topic found is "Drive Circuit". So we can conclude that an important starting point to suppress flicker is the operating mode of the LED. Unfortunately, that does not tell us much more about the technologies actually used. The next most frequent topics are "Light Emitting Diode" and "Light Source". These terms can occur both in the problem definition and in the solution but do not describe the used technology any further.

It gets more interesting looking at the term "AC Power, AC Voltage". Obviously many patents focus on flicker caused by the use of AC mains voltage for the operation of

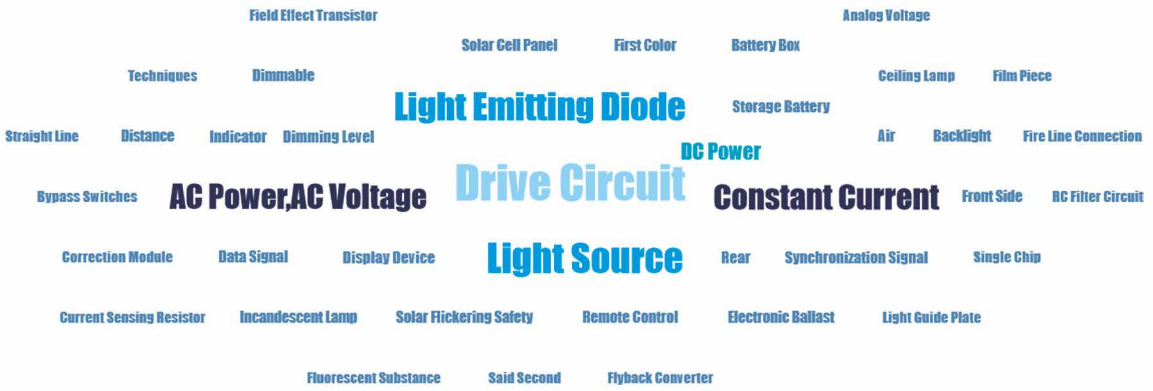

Figure 5:
"Word Cloud" for all applications regarding flicker suppression. The bigger the characters are, the more frequently the term is used. The terms should express the problem and solution described in the patents

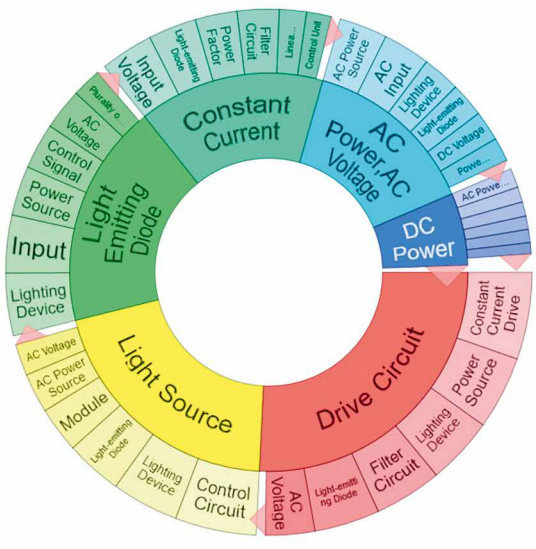

Figure 6:
"Innovation Wheel" for all applications regarding flicker suppression. The figure shows frequently used terms in context. The size of the sectors indicate how often the terms appear in context

LEDs. "DC Power" and "Constant Current" may indicate a solution, but are again not specific enough to understand the solution in detail.

We can also ask in what combination main topics are related to other topics. One possible depiction for results from this analysis is the "Innovation Wheel". The main topics from the Word Cloud analysis are presented in an inner circle. In an outer circle further topics are presented, which are associated with the respective main topic. This kind of analysis is shown in figure 6 for all patents regarding flicker suppression.

Let's take a look at the topics linked to the main topic "Drive Current". Here we find terms like "Power Source", "Lighting Device", "Filter Circuit" and "Light Emitting Diode". These terms do not help to specify the main topic, since these terms are in a natural close relationship to the "drive circuit" and therefore do not provide any additional information about the technologies used. The connection with "Constant Current Drive" and "AC Voltage" are probably technologically linked to the main topic, but do not bring any significant new information, as these two points have already been listed as main topics.

Taking a closer view of the information associated with the other main themes, similar results are obtained. Most of the topics associated with a main topic appear to be those related to the current state of the art. So they do not provide any further information on the invention described in the patent.

If you take a closer look at several topics appearing frequently in context, these topic clusters can be used to draw a two-dimensional landscape, where the mountains correspond to the topic clusters and their height corresponds to the frequency of appearance (Figure 7). Here, too, more general and overlapping terms, appear in the topic clusters. It seems that conceptual terms describing the solution are too rare to become apparent. The variety of solutions is too large and the terms associated with a particular technology are too rare.

Technology Fields of Top Applicants

In order to examine only a part of this variety of solutions, we applied AI methods to the applications of individual manufacturers. It has been found that even an examination of the Word Clouds delivers helpful hints to the problem formulation and the applied technologies. Innovation Wheel and Landscape did not work very well due to the small number of evaluated patents (less than 20 per manufacturer).

The central term in the Word Cloud for Sharp (Figure 8) is "Current Extraction", which suggests special driver technology. The frequently used terms "AC Power" and "Phase Control Type Dimmer" suggest that the problem could be solved by the inventions: by using a phase dimmer in the AC power supply, flicker may occur which is solved by a special circuit technique. The concentration on a single subject area shown in the Word Cloud is also reflected by the patent activity shown in figure 4 (all applications presumably part of a single project).

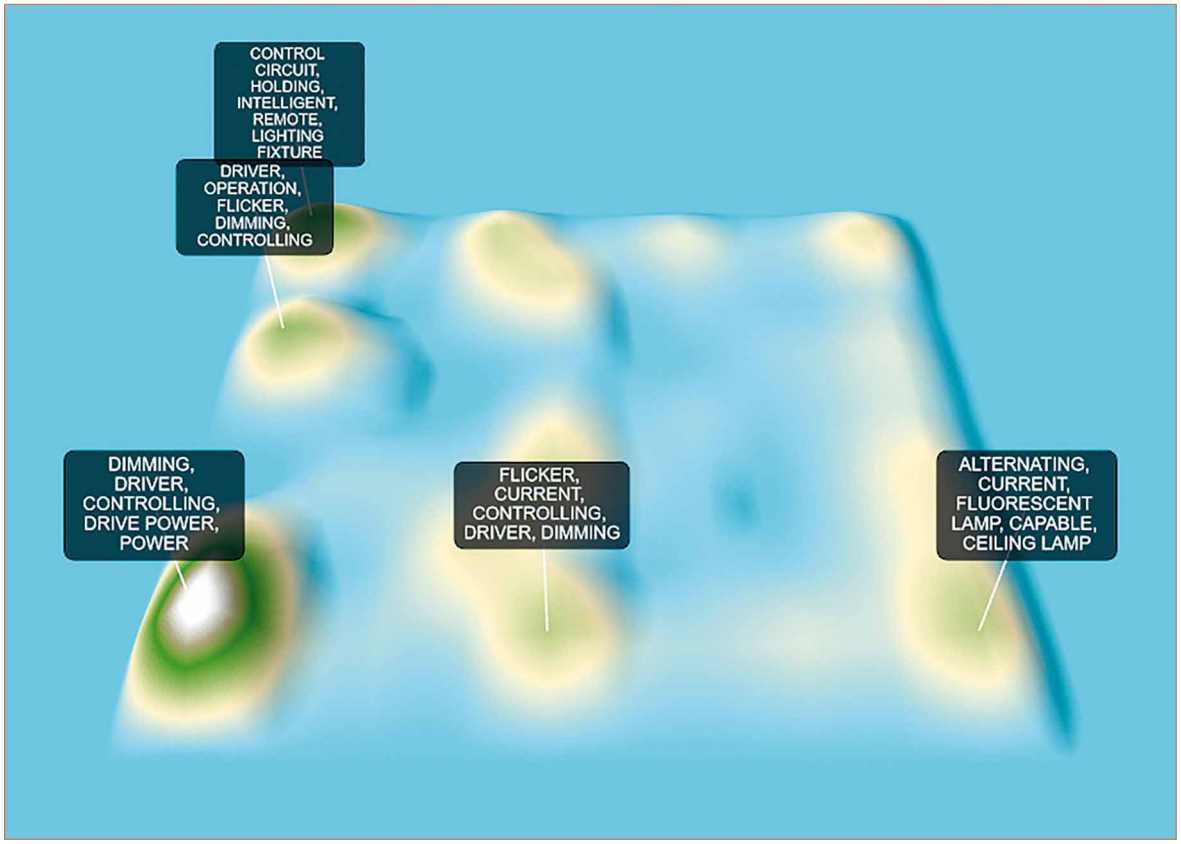

Figure 7:
"Innovation Landscape" gives a representation of groups of terms that appear in context. The peaks indicate groups that are frequently used together, the distance of peaks indicate how close groups are related to each other

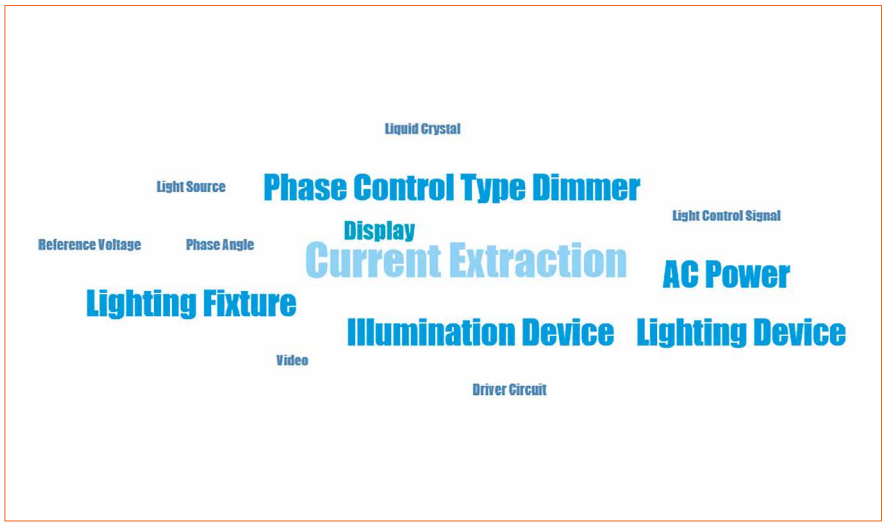

Figure 8: Word Cloud for Sharp patent applications. The terms "Current Extraction", "Phase Control Type Dimmer" and Ac Power" give hints about the problems and solutions the applications deal with

Figure 9: Word Cloud for Sichuan Sunfor Light applications. The terms "Lamp Shade, Fluorescent Powder", "White LED Lighting Device" and "Service Life" describe the main topics of the applications

The Word Cloud of the Sichuan Sunfor Light patents (Figure 9) also provides important clues to the protected technology. Quite often "Lamp Shade" is used in direct conjunction with "Fluorescent Powder". Also the term "White LED Lighting Device" appears frequently. The patented solutions thus use a remote phosphor technology, wherein the phosphor is attached to the shade. It seems to be obvious that a special phosphor supports flicker suppression. Again, the Word Cloud supports the assumption that the patents were filed to cover the technology field of an invention (as already shown in the interpretation of Figure 4).

Based on the Word Clouds of applications from Philips and Seoul Semiconductor no direct conclusions can be drawn on the technologies used. This may be due to the fact that in both cases, the applications are spread over long periods and therefore they focused on different problems and solutions, which are not recognized as significant by the AI software.

Figure 10: **Some very critical applications in respect to flicker are here shown**

Conclusions

Patent analysis tools have been used to create an overview on flicker suppression technologies. Technology S-curve analysis has been derived from a statistical application analysis. It shows, that flicker suppression technologies have reached maturity and are now on the cusp of old age. Further development will lead only to incremental innovations (unless new flicker suppression techniques are invented).

Activities of applicants can follow the S-curve (e.g. Sharp, Sichuan Sunfor Light) or can be spread more or less evenly over time (e.g. Philips, Seoul Semiconductor). The application pattern gives a clear hint of the strategy and how these companies deal with innovation (at least for this specific topic).

Artificial intelligence algorithms gave us the chance to deduce how inventors try to suppress flicker. We found two very different approaches: flicker suppression by special circuit design in the driver or by using special phosphors. AI-algorithms for patent analysis seem to still be in a very early stage and improvement could be very helpful for getting reliable information on patented solutions. ■

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Swiss university spin-off, Insolight, is marketing a robust solution that allows changing beam direction. The image shows the demonstrator which is used to explain the mechanics and fundamental working principle

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TECH-TALKS BREGENZ

David Schmidmayr, Co-Founder & General Manager at SANlight

Two friends and passionate hobby gardeners, David Schmidmayr and Martin Anker, founded SANlight immediately after studying Mechatronics at the University of Applied Sciences, Dornbirn. The two innovative entrepreneurs work together with scientists from botanical institutes to provide adequate solutions in horticulture lighting. David Schmidmayr talks about challenges and opportunities, how the company was founded and how it evolved, cooperations and future prospects.

RESEARCH

"Best Papers" at LpS: VLC Luminaire - Visible Light Communication

The Institute of Electronics at NTB has developed an intelligent luminaire system that is capable of organizing itself, controlling brightness and optimizing power consumption using presence detectors and Visible Light Communication (VLC). The LEDs allow information to be modulated into visible light without additional electronics. The information is received via an integrated photodiode and requires little additional hardware. With this setup, a communication without radio and without special modules can be realized. As part of this project, a system with a working range of 20 meters was developed.

TECHNOLOGIES

Material Considerations for UV Optical Elements in Horticultural Lighting

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. This article will discuss the performance considerations of various UV-transmitting materials and how application challenges are addressed by integrating optical elements.

SPECIAL APPLICATIONS

LED Driver for High Power Machine Vision Flash

Machine vision systems use very short flashes of intense light to produce high speed images used in a wide variety of data processing applications. One challenge in all of these systems is creating the very high current and short-term (microseconds) LED camera flash waveforms. The drive currents for the LEDs may rise above 1 A while the LED on-times shrink to microseconds. An increasing challenge that most conventional LED drivers with high speed PWM capabilities may not efficiently master. A viable solution is proposed and discussed.

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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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