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LpR

The Global Information Hub for Lighting Technologies
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TTB: Dr. Wilfried Pohl

Research: Spectral Rayfiles & Medical Applications

Characterization & Quality: UV & Shop Lighting

Technologies: Laser & Quantum Dots

Creativity like yours deserves the ultimate spotlight.

Sometimes, the smallest things can yield the biggest breakthroughs. That's certainly true when it comes to Lumileds LUXEON Chip-on-Board (CoB) LEDs. With an unmatched combination of superior performance and competitive pricing, these compact light engines ensure you always get more than you pay for. In addition to unbeatable value, this family boasts the widest selection on the market, so you'll never need to settle—even in the most challenging luminaire designs. When you're ready to take your creativity further, start with the only CoB LEDs designed to get you there.

See more. **lumileds.com/cob**

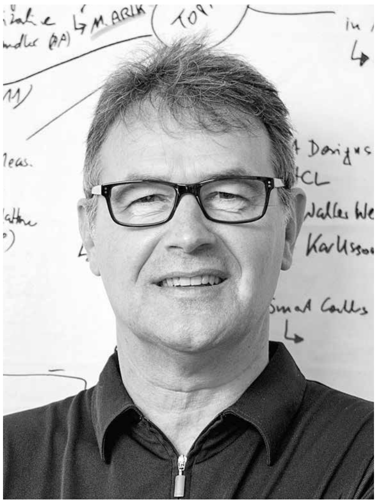
LUXEON CoB LEDs

- Optimized for applications that require the highest efficacy—including fashion, retail and hospitality
- Industry's lowest thermal resistance—enabling smaller, less expensive systems
- Robust substrates for high reliability and low manufacturing waste

LUMILEDS

LUMILEDS ILLUMINATION LEDs

LUXEON HIGH POWER LEDs • LUXEON MID POWER LEDs • **LUXEON CoB LEDs** • LUXEON COLOR LEDs • LUXEON UV LEDs • MATRIX PLATFORM



LpS 2017 & TiL 2017 - The Lighting Events

I would like to take this opportunity to give you some important updates for the events coming up in September.

We are proud to release this year's event program (in this issue), for what will be the greatest LpS to date. Global experts from industry and research will join over 1600 delegates and 100 exhibitors in Bregenz this year to focus on multiple lighting applications such as Human Centric Lighting, Transportation, Agriculture, Healthcare and many more. These chosen specialists will be sharing their future visions, innovative technologies, trend insights and research findings in over 100 carefully selected lectures. We have been building up to this for 7 years; LpS 2017 will be something truly unique! We are bringing together the very best minds from the lighting industry and research, for what I believe will be 3 unforgettable days that will explore and develop the lighting technologies of tomorrow.

TiL 2017 (Trends in Lighting: Smart Lighting Forum & Show) launched this year, expects 2000 visitors joined by leading light experts from international companies including Zaha Hadid Architects, Amazon, Philips Lighting, Osram, Zumtobel Group. This event has been designed to focus on, and to debate, all the big questions and best practice in the fields of Human Centric Lighting, Connected Lighting, Smart Controls, IoT and Light as a Service. Tailored for a delegation of architects, lighting consultants, lighting manufacturers, electrical consultants and lighting designers, TiL 2017 is set to be a truly immersive experience and one that will help to close the gap between application, design and technology.

We chose to launch Trends in Lighting in 2017 because we believe the possibilities of light have reached a zenith. The users of light, the designers, the architects, the manufacturers and the consultants have almost limitless possibilities when working with light due to the power of modern technology. We want to immerse every attendee into light and have people recognize light's potential. In addition, we want to explore light to contribute to sustainability and well-being, now and in the future.

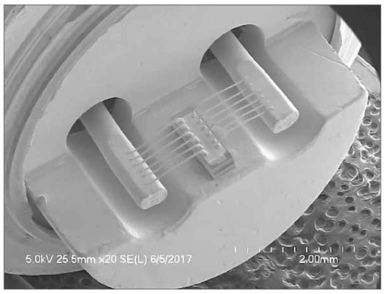
We believe that all great things deserve recognition and that was the impetus for the TiL System Award, the LpS Technology Award, and the LED professional Scientific Award; all designed to celebrate excellence in light. The awards make it possible to showcase and put a spotlight on the latest achievements in lighting.

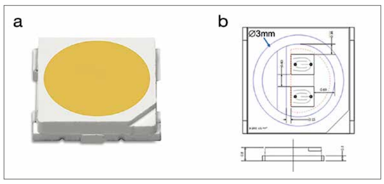
Luger Research also announces the first scientific lighting partnership network, for research experts and leaders in the lighting industry, which will be presented at the LpS event for the first time. The scientific partnership was created to form an active network that will strengthen and build the connections between universities, research laboratories and industry. The scientific partnership's mission is to enable and secure the continued development of innovation in lighting technology. Founding members are: EVATEG, Joanneum Research, Steinbeis Transferzentrum, Holst Centre, CSEM, University of Edinburgh, University of Padova and KTH.

Looking forward to seeing you in Bregenz. In the meantime, enjoy reading through the LpR 63.

Yours Sincerely,

Siegfried Luger
Publisher, LED professional





ADVERTISING INDEX

Arno Grabher-Meyer

Arno Grabher-Meyer originally studied biology at the University of Innsbruck. He was involved in several scientific documentation projects for the Alpenzoo (Alpine Zoo) and a documentary film for the BBC with David Attenborough. He worked as a freelance photographer for the Inatura (Museum for Nature, Humans and Technology) in Dornbirn.

He earned his engineering degree through continued education and in 2005 went to work for Luger Research. Here Arno worked on several LED lighting research projects in conjunction with the Austrian Competence Center Light.

His job as Chief Editor started in 2006 when Luger Research initiated LED professional. Part of this multi-faceted job is being responsible for the editorial content of the magazine and online news.

BRAVE NEW WORLD AND THE NEW DUALISM OF LIGHT(ING)

The lighting business has been quite predictable over a long period of time. Technical changes were introduced slowly, dominated by a handful of leading companies, and mostly due to new, but not disruptive light sources. The life of engineers was mainly determined by a manageable number of parameters: Lighting requirements, light source parameters, costs, product dimensions, and the odd, required feature.

The introduction of LEDs as a light source was a disruptive event in the comparatively "placid" life of an engineer in the lighting business. While the concomitant digitalization was seen as an advantage for the industry because of the seemingly endless number of new lighting opportunities, making the new "digital" light source work properly with the old analogue technology was anything but trivial. In addition, the industry now followed the rules of the semiconductor business: Faster production cycles, unfamiliar technologies, requests for added value, to name just a few.
But this was just the beginning.

Added value became important for a company to survive in the new semiconductor shaped environment. But it's a challenge for employees - including the engineers. Human Centric Lighting (HCL) and Internet of Things (IoT) are the new bearers of hope for the big businesses. While HCL needs advanced controls options and asks for automation to provide added value, which means additional costs, the implementation of IoT seems to be the logical way to go. The lighting devices as enablers and central components should open the door to this "brave new world" of services. Selling "lighting as a service", and more so, lighting products as "carriers of a service" is a technological challenge.

The electronics engineer for controls is especially confronted with technical issues that have nothing to do with lighting while having to think about the best way to control the light - hopefully the main function of a luminaire or lighting system. On the other hand, they need to ensure that the implemented added value works smoothly and does not add too many costs, does not make commissioning of the lighting system more complicated, but rather, even helps to simplify this process. System complexity is exploding, while user friendliness must be improved.

As if these demands are not enough, the number of different, barely compatible systems that need to be connected is meanwhile huge: IPv6, BLE, ZigBee, etc. Choosing the right system, solving security issues and privacy requirements that differ from country to country is also necessary. These are all questions that the earlier generation of lighting engineers didn't have to worry about.

LiFi technology is knocking loudly on the door, promoted by different groups. While still under development and more of a niche product, the commercial implementation of this exciting technology in lighting products carries new challenges with it. Merging two functions using one carrier, visible light, concerns both the optical engineer and electronics engineer. A very high frequency modulation for data transmission versus flicker-free illumination, convenient light levels and proper spatial light distribution are properties that seem contradictory. It will be exciting to see the solutions for commercial products.

Referring to the wave-particle dualism, we recognize this as "the dualism of lighting". In any scenario, at least two independent functions will challenge the engineer. One may ask if being an engineer in this business is a good idea. But even though it sounds complicated and cumbersome - almost impossible - this job has never before been so interesting, rich in variety, and exciting. The chance to create something unique and exceptional was never bigger for the lighting engineer than it is today. ■

A.G-M

TiL TRENDS IN LIGHTING®

Experience the Future of Lighting

CONNECTED LIGHTING FORUM & SHOW

TiL is an immersive, international event designed for those at the forefront of lighting. *TiL* addresses the big questions being asked in modern light design and technologies.

TiL 2018 **SEPT 25 – 27** Bregenz Festspielhaus

Organized by Luger Research e.U.

Plessey Extends LED Portfolio with MIDION™ Mid-Power LEDs

Plessey announced that it is extending its LED product portfolio into a variety of mid-power LED packages. Plessey now offers lighting equipment manufacturers a complete and competitive portfolio of solid-state lighting products and solutions for all general illumination market applications.

Targeting all general lighting applications, Plessey extends its LED product portfolio into a variety of mid-power LED packages

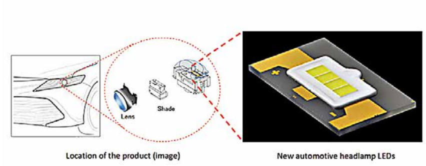
Plessey's mid-power LED product offering, called MIDION™, includes products with leading-edge performance with efficacies up to 210 lm/W, modules with zero flicker and LED components at 90 CRI. All lumen maintenance is certified to LM-80 and offered in standard color temperatures for all general lighting applications. Available throughout the portfolio are various high CRI, high-voltage, super-efficient, and three-step MacAdam ellipse (SCDM) as standard and single-step MacAdam ellipse (SCDM) reels available on request.

Plessey's MIDION™LED mid-power series Giuliano Cassataro, Plessey's Sales Director, said, "We are very excited about the launch of the MIDION™ product range which augments and enhances our existing LUCIAN™ range of high power LED products. Plessey has established itself as a credible European-based manufacturer of LEDs with best in class performance and competitive pricing. Our new extended offering of mid-power LEDs enables us to address an even wider range of lighting applications."

The MIDION™ range features the ultra-small dotLED™ plus variants of the industry standard 2835, 3014, 3030, 5050, and 5630 PLCC packages. The series spans color temperatures from 2700-6500 K with nominal flux levels from 20-140 lm and a typical viewing angle of 120°.

World-Class Luminance Automotive Headlamp LEDs from Toyoda Gosei

Toyoda Gosei Co., Ltd. has developed its first automotive headlamp LED as a new LED product. According to in-house tests, these LEDs achieve world-class luminance and low energy consumption.



Toyoda Gosei's flip-chip based automotive LEDs deliver 2,300 lm and can be used in bi-functional headlamp systems

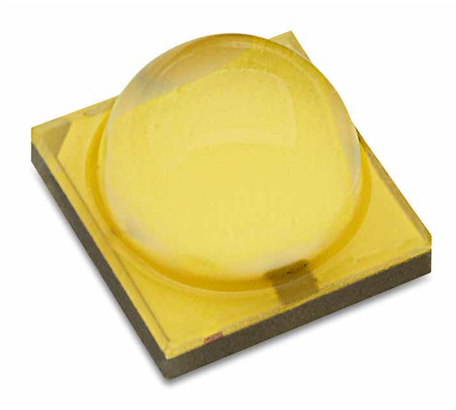
Toyoda Gosei has applied the blue LED crystal growth technology it developed over many years to improve the structure of gallium nitride (GaN) crystals in this new LED light source, with flip-chip technology adopted for good heat dissipation. These headlamp LEDs can achieve high luminance of 2,300 lm and can be used in bi-functional systems that produce both low and high beams from a single light source.

Headlamps employing these LEDs will help reduce energy consumption in electric vehicles, fuel cell vehicles and other next-generation vehicles, and are expected to come into widespread use in the future as an environmentally-friendly product. Toyoda Gosei will continue to develop various types of headlamp LED light sources to meet customer needs.

Lumileds Transforms Single Die LED High Power Category

Lumileds revealed its highest flux density LED yet, the Luxeon V. Redefining the possibilities of light in a compact 4.0x4.0 mm footprint, Luxeon V can be driven harder than other LEDs in its class due to revolutionary new die and packaging technologies. Luxeon V produces more than 1,700 lumens at 5700 K and 70 CRI (4.8 A) - 50% higher output than competing LEDs.

"Luxeon V enables fixture designs that were previously unattainable for stadium and area lighting, torch and other portables because of the unique combination of high efficacy at high drive current with extremely low thermal resistance and optimized radiation pattern," said Kathleen Hartnett, Senior Director, Product Marketing at Lumileds.



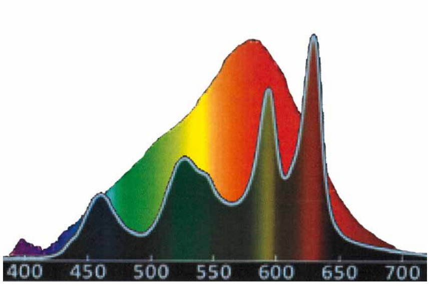
LUXEON V fuels the design of the most compact and innovative high flux density lighting fixtures with 50% higher lumens and 60% lower thermal resistance compared to competitors

Luxeon V LEDs leverage the strengths of Lumileds next generation Patterned Sapphire Substrate (PSS) Chip Scale Packaging (CSP) technology - high efficacy at high drive currents, higher max drive current and higher lm/mm^2. The nominal drive current is 1.4 A, and the LEDs may be driven at up to 4.8 A - 60% higher than competing emitters. With the lowest thermal resistance in the industry of 0.8 K/W, designers can use smaller heat sinks for sleeker, more compact fixtures. Luxeon V LEDs feature a standard 3-stripe footprint for ease of design and assembly and is offered in a range of CCTs including 3000 K to 6500 K.

euroLighting LED with Sunlight Similar Spectrum

EuroLighting has taken over the European sales rights for sunlight similar LED from the Korean manufacturer ALLIX and started with the samples delivery of such LED chips. They are available now in many package sizes and in CoB.

The chip LEDs with the sunlight similar spectrum are patent protected in Europe, Korea, USA and China by several patents. The new LED is available in two series: Xenoled I and Xenoled II. The difference between both series is, that Xenoled I is using a blue chip as basis and different phosphor colors. These SMD chips have a high CRI up to 98 and a high RF value up to 96 and no blue spikes.



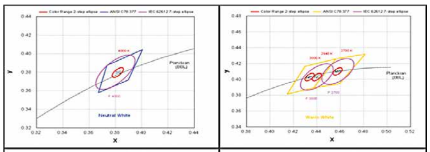
Comparison between a multi-chip LED solution and the Allix Xenoled technology that has a smooth continuous spectrum like the sun, while the multichip solution also shows no significant blue spike, but it has a poor SPD

The series Xenoled II are produced on the basis of violet chips and with several phosphor colors. They produce an excellent sunlight similar spectrum and reduced dangerous blue spikes. The Xenoled II can be offered with highest CRI value up to 99 and RF values of 98. Both component series are available in CoB and all SMD package sizes. Xenoled I is especially useful for shops who request true colors: bakery, vegetable, fruits, and so on, but also for cosmetic shops, beauty salons, and photographic applications.

Xenoled II is suitable for the illumination of museums and art galleries, because of the missing blue wavelengths (bleaching the colors on pictures) as well for medical and chirurgical applications. The picture shows how different the spectral power distribution of a standard LED compared to the new invented Allix with its spectrum similar to the sunlight is. ■

ProLight Introduces New CoB G-II Series with Higher Lumens & CRI

Taiwan high power LED manufacturer, ProLight Opto, presents the new CoB G-II series, which has 4 series including 11 items. Since ProLight announced CoB series with 2-step MacAdam ellipse in 2015. ProLight's newly upgraded CoB G-II series, not only maintained 2-step MacAdam ellipse, but also increased flux by up to 5-10% through reselection and improvement of materials such as dies. The wattage range 7-260 W covers application from light bulb to mercury lamp.



	2-Step in Neutral White		2-Step in Warm White	
	PACJ	PACK	PACL	PACM
Watt	7 / 14 / 21 / 28W	35 / 42 / 57 W	78 / 86 /115 W	260W
Size	13.5*13.5*0.9mm	19*19*0.9mm	28*28*0.9mm	38*328*0.9mm
CRI	70-95	70-95	70-95	70-95

ProLight Opto's new CoB G-II Series LEDs offer high performance while providing high CRI and narrow 2-step MacAdam ellipse binning

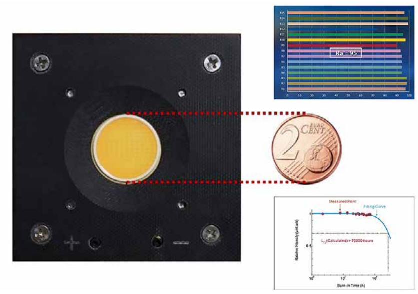
The new generation CoB G-II series delivers high luminous flux and High CRI 95. The superficial illuminating nature of ProEngine makes them the preference in Par lighting, typical applications include commercial down lighting, LED bulb, accent lighting, ceiling lighting and spot lighting.

As the market expects higher requirement for higher CoB specification, ProLight's R&D director expressed, CoB G-II series not only maintained the accurate color temperature binning, but also introduced new CoB product with ultrahigh color rendering to above CRI 95 (in neutral white and warm white), which can be used for studio light to show the best color saturation. Furthermore, the footprint and circuit is maintained to be the same as its predecessor first generation CoB, which can be replaced very easily without any changes on driver or components. It is the best solution to upgrade the performance of current lighting products. Of course, all series have passed LM-80 and TM-21 to ensure reliability.

ProLight devotes itself into LED lighting for over 12 years, in addition to CoB general lighting series, it also provides CoB commercial series for Food Fresh and True White series to provide a wider range of LED solution for different lighting application. ■

Yuji LED Introduces World's Highest Lumen Density CoB Series

After years of research and development, Yuji LED proudly presents their high CRI high reliability CoB with the world's highest lumen density: A chip on board (CoB) light source has a small emitting surface (LES) and large luminous flux, thus it is usually used in directional lighting fixtures, and is always the best choice for minimizing the fixture's size. This means, however, that more heat will be generated, the luminous efficiency will be largely compromised, and that it may lead to the failure of the CoB. Hence, when designing a CoB, it is always the key point to improve the luminous flux and the reliability while controlling the LES. Based on this principle, Yuji LED's High Lumen Density High CRI CoB Series was developed.



LES comparison for YUJILEDS' High Density High CRI CoB. CRI test result of 5600 K CoB sample (top inset). Burn-in test and lifetime calculation result of High Density High Power CoB (bottom inset)

With an LES diameter of only 19 mm, this CoB can achieve a luminous flux of 24,000 lm at 5600 K, which is a luminous flux density of 88 lm/mm^2. Compared to 76 similar products by 15 well-known manufacturers on the market, Yuji LED CoB has an overwhelming advantage of 60 lm/mm^2 above the average. That is to say, when emitting the same amount of luminous flux, Yuji LED CoB has an LES only one fourth the size of other products. That creates large space for further optic design.

To tackle the heat dissipation issue, a flip chip structure and eutectic welding technology are adopted in our High Lumen Density High CRI CoB, where the chip is soldered directly onto the substrate. In this way, the heat can be transferred directly to the substrate, and the efficiency can be largely increased. Second, this Yuji LED CoB has AlN substrate with a heat transfer efficiency as high as about 300 W/m·K, which is two times that of Al substrate, and six times that of Al_2O3 substrate.

Additionally, the unique chip alignment design of Yuji LED CoB ensures that the heat is dissipated equally from the chip to the substrate, thus improving the reliability of the product. Our full power burn-in test on samples of three different color temperatures shows, after 6,000 hours, the average decay of the examples is less than 1.5%, and the estimated total lifespan (L70) is over 70,000 hours.

For white LEDs using the "phosphor excited by blue light" solution, the color rendering performance is decided by three factors: The phosphor properties, the mixing ratio of the phosphors and the packaging process technology. These are especially important for high lumen products, because the excited phosphor also produce large amount of heat. Yuji developed the post-treatment process, successfully improving the thermal reliability of the phosphors. Then a unique packaging technology was adopted, by which the heat is efficiently dissipated through the chip and the encapsulant. Statistics proves extremely high color rendering ability and high reliability of this CoB. It has a CRI (Ra) as high as 95 even at a CCT of 5600 K. Besides, after 6000 hours of burn-in test, the product shows a color temperature shift smaller than ±50 K, and the chromaticity shift is less than ±0.001.

To meet the light requirements of different places, the YUJILEDS High Lumen Density High CRI CoB Series also released another member, which has an LES diameter of 9 mm and luminous flux of 6,000-8,000 lm. In the near future, Yuji plans to offer more choices, including a 6 mm diameter product with 3,000 lm flux and a 30 mm one with 60,000 lm flux.

As an LED light source manufacturer, Yuji LED always focuses on light quality, and has been dedicated to the research and production of high CRI packaged LEDs since it was founded. In recent years, apart from CRI performance, Yuji has expanded its spectrum to take design into consideration, trying to provide more possibilities and convenience for downstream manufacturers. The latest High Lumen Density High CRI CoB Series was born to actualize this idea. ■

Seoul Semiconductor and Toshiba Materials - SunLike LED Light

Seoul Semiconductor, a global innovator of LED products and technology, has developed a new LED technology that produces light that closely matches the spectrum of natural sunlight. Announced at a press conference in Frankfurt, Germany on June 26, 2017, the new SunLike Series natural spectrum LED technology was co-developed by Seoul Semiconductor and Toshiba Materials.

Comparison of the different appearances of a painting illuminated with (a) TRI-R LED technology, (b) standard white LED technology

Back to natural light

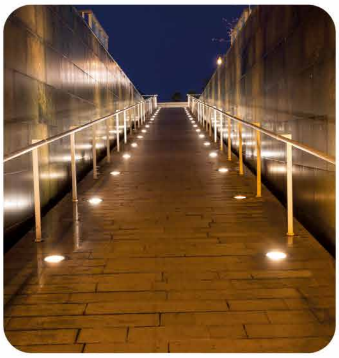
Human beings have lived under natural sunlight for tens of thousands of years, and only began using lanterns in the third century BCE. The use of white LEDs for general illumination began less than 20 years ago,












but has spread rapidly around the world due to the high efficiency and cost savings of LED lighting. However, low cost and brightness has been given priority over the quality of light, thus the light from conventional LEDs has a different characteristic from that of natural sunlight, which matches the human biorhythm.

The SunLike Series LED technology closely matches the spectrum of natural sunlight that human have enjoyed for thousands of years. It maximizes the advantage of natural light and minimizes the shortcomings of artificial light sources, providing light more like natural sunlight. This natural spectrum of light is achieved by combining SSC's world-class LED chip technology with Toshiba Materials' leading TRI-R phosphor compound technology.

Minimizing the side-effects of blue light
Because SunLike Series LEDs are designed to deliver light that closely matches the natural spectrum of sunlight, they provide an optimized light source for human centric lighting that maximizes benefits of natural light while minimizing the negative side effects of artificial light sources.

Some recent studies from Harvard [1] and other major universities have suggested that blue LED chips, used in most commercial LEDs to create visible light, provide positive stimulation to the human eye that increases alertness and elevates mood when viewed during daytime hours. However, these blue LEDs create a blue light "spike" in the light output of an LED that may produce negative effects when viewed for prolonged periods during night-time hours by interfering with natural human biorhythms. The SunLike Series natural spectrum LED technology employs a purple LED in conjunction with the TRI-R phosphor compound to minimize the blue light "spike" that is characteristic of typical LED light sources, producing a light output that closely matches the spectrum of natural sunlight to deliver a healthier light experience.

SunLike's world-class color reproduction
Because the amount of blue light that our eyes can accept is limited, blue light above the limit entering the eye is scattered. When this scattering phenomenon occurs, the light is diffused, and as a result, the texture and color of objects are distorted. Also, excess blue light can over-stimulate these retinal cells in the eye, and may cause eyestrain and loss of concentration. However, since SunLike Series LEDs implement the spectrum closest to the sunlight, they more accurately represent the color and texture of the object in natural light without the negative effects of excessive blue light on the eye or human biorhythms. Several products in which Toshiba's TRI-R technology were incorporated have already been applied to lighting in Milan Fashion Week and illuminating fine art paintings in museum settings. ■

Samsung's New Q-series LED Improves Premium Indoor Lighting Efficiency

Samsung Electronics Co., Ltd., a world leader in advanced digital component solutions, today announced that it is launching the "Q-series," a new line-up of LED linear modules for use in premium indoor luminaire applications where an exceptionally high level of light efficacy is required.

Samsung's new Q-series linear LED modules offer superior efficacy to improve premium indoor lighting

Samsung's Q-series line-up includes:

Reg.	Type	Model	Lum. Flux [lm]	Efficacy [lm/W]	Cond. [mA | V]
NA	4 ft.	LT-QB22A	4,000		450, 43.8
	2 ft.	LT-Q562A	2,000		450, 21.9
	1 ft.	LT-Q282A	1,000	203	450, 11.0
EU	2 ft.	LT-Q562B	2,000		180 54.8
	1 ft.	LT-Q282B	1,000		180 27.4

The Q-series features 200 lumens per watt (lm/W) of light efficacy, which is the highest efficacy level among LED linear modules anywhere. The new modules are the first to incorporate the LM301B, Samsung's recently announced mid-power family of LED package.

This allows LED lighting fixtures using the new modules to reach more than 150 lm/W, enabled through an optical efficiency level of approximately 86 percent and LED driver efficiency of about 88 percent. The Q-series' performance levels are ideally suited to meet DLC Premium technical standards, which require higher efficacy and lumen maintenance specifications than the DLC Standard classification.

The new Q-series modules come in one-, two- and four-foot sizes, and can be combined linearly to achieve any desired length. There are two sets of modules: Q-series modules for the North American market are UL certified, while those for the European market have CE certification.

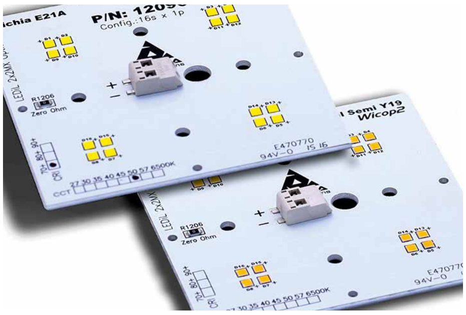
The Q-series has the same form factor as Samsung's other modules for easy retrofitting with existing LED luminaires and is now available through Samsung's worldwide LED sales network.

With the addition of the premium Q-series line-up, Samsung now offers five families of LED lighting modules (H-, M-, Q-, S- and V-series) to meet most indoor LED lighting needs. ■

Adura LED Solutions - New CSP-Based 2x2MX LED Modules

Adura LED Solutions has launched a line-up of Ultra high performance chip-scale package LED modules based on Nichia E21 and Seoul Semiconductor Y22 for outdoor and indoor applications.

"Our new Ultra high performance CSP LED modules provide an optimal thermal performance for lighting manufacturers who seek highly compatible and reliable MCPCB and LED components," says Abdul Aslami, Sales and Marketing Director at Adura. High lumen applications such as outdoor and industrial lighting benefit from the high drive current capabilities and robust high power architecture of Adura Ultra high performance low thermal resistance MCPCB Technology. In addition, the MCPCB boards are designed where each lens have a cluster of four small light CSP source with high lumen density of E 21 or Y22 CSP LED.



Adura LED Solutions new MC12096 modules are based on CSP LED package from both Nichia and Seoul Semiconductor

The new 2x2MX CSP LED modules are available in form factors (2.874" x 2.874" / 73x73 mm) and are designed to be compatible with LEDiL 2x2MX STRADA Lens family.

The MC12096 modules are based on CSP LED package and both Nichia E21 and Seoul Semiconductor Y22 CSP LEDs has completed 10,000hrs LM-80 test at the max current tested at1050mA. The Adura 12096 CSP Module is offered in color rendering indexes (CRIs) of 70+, 80+ and 90+ and correlated color temperature (CCT) of 2700 K - 6500 K. ■

Fulham Offers Luminaire Designers Optimized LED Modules

Whilst there is a wide variety of standard sizes and standard powers and outputs of LED modules available on the market, most luminaire designers would agree that bespoke made-to-measure LED modules are preferable from a performance and design perspective. This is where Fulham's service in providing bespoke LED modules comes into its own.

In addition to standard LED modules, Fulham offers bespoke made-to-measure LED modules

Fulham is not simply a PCB manufacturer placing LED semi-conductor components onto boards, but is a leading manufacturer of LED drivers. This means that luminaire manufacturers can work with Fulham to the exact design criteria required, ensuring that the best fit, shape, fixing, size and PCB material is used, with the best suited LEDs and array of LEDs and layouts to match with the most optimized driver combination. In this way there are no compromises of the sort that would inevitably come into play if the luminaire manufacturer was to select a standard, off-the-shelf LED module.

Fulham has much experience in working directly with luminaire manufacturers to produce these bespoke LED modules, matching them to drivers to result in best possible optimization of efficiency, light output, life, reliability and lumen maintenance. Such compatibility results in the lowest cost base. Such highly specific solutions give luminaire manufacturers the best commercial advantage.

Fulham's LED modules are designed for optimum light output and efficiency, and PCB material selection ensures the best thermal management of the LED components for the assurance of extended LED life. Luminaire designers can of course choose any shape; linear, square, round, half round etc. with a wide choice of LED color temperatures and CRI. Optional diffusers are also available. ■

Getting the Light Level Just Right with RECOM's New RACT Series Drivers

Recom introduces four new LED drivers with 9 W, 12 W, 18 W and 25 W outputs. They deliver 1% to 100% leading-edge or trailing-edge TRIAC-controlled dimming at the market's most affordable prices. These LED drivers are designed for either retrofit or new installations and allow the user to set the lighting atmosphere and mood in homes, spotlighting and furniture installations.

With the new RACT series members, Recom offers low cost but high quality LED drivers with a wide dimming range

Dual Voltage

AC PLCC Module

0~10 Dimming Triac Dimming

Title 24 | CRI 90 | Flicker Free

Working on differnet voltage (120V/230V and 120V/277V) in various countries, this module also provides flicker-free solution (Percent flicker <20%)

Dim to Warm

AC PLCC Module

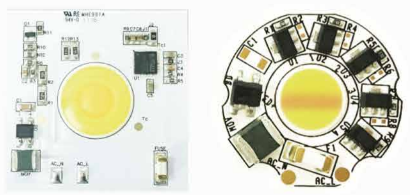
Triac Dimming

Title 24 | CRI 90 | Flicker Free

Adjusting brightness from 100% to 10% without flicker (Percent flicker <20%) is possible. This module with high CRI is also sufficient to meet Title 24.

Dim to Warm

AC COB Module



Triac Dimming

CRI 90

Showing the same effect of halogen lamps, it delivers uniform light disdribution. It's also able to adjust color temperature between 2000K and 3000K.

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The new RACT series are low cost, TRIAC-dimmable LED drivers available with constant current outputs ranging from 300 mA up to 1,400 mA. Both leading and trailing edge phase angle control makes them suitable for many standard dimmers for a wide range of applications. The RACT series are ideal for indoor locations up to 50°C ambient temperature and are certified for building into furniture for applications such as dimmable shelf lighting, cove lighting or accent lighting. Integrated cable clamps and extra-large screw terminals make for an easy installation.

The Class II (double insulated) design means that no earth connection is required. They are CE marked (LVD + EMC + RoHS) and have IEC61347-1/IEC61347-2-13 CB reports. Recom offers a 3 year warranty as standard. ■

Tridonic - Compact LED Driver for Five Adjustable Output Currents

Tridonic is introducing a highly flexible driver range. Combined with the range of SLE LED spotlight modules it will make a perfectly matched system especially suitable for architectural lighting and illumination of retail spaces. With five pre-adjustable output currents, the drivers meet the requirements of a wide variety of applications.

The output currents of the flexC SC Advanced can be selected by simply inserting an Advanced plug

The flexC SC Advanced constant current drivers are available in 5 wattages, each with a choice of five output currents ranging from 350 mA to 1,400 mA. Thus, the new drivers are suitable for all standard currents in spotlights and downlights.

The output currents can be selected by simply inserting an ADVANCED plug. In order to avoid mistakes, the plugs are color-coded to indicate their Ω values. Moreover, a plug can be inserted in the driver quickly and safely, as compared to the miniature rotary switches usually found in drivers - the required current can be selected easily and safely using pre-defined mA increments.

Most applications in the field run within an output range between 350 mA and 1,050 mA. Within this range, the flexC SC Advanced drivers come with a new compact housing size of 97x43x30 mm to match the miniaturization of spotlights and downlights. They are perfectly suited for small track boxes and unobtrusive spotlight design. Additional click-on strain relief devices turn the drivers into independent Class II drivers for recessed downlights that can be adjusted to the most diverse applications. With just one SLE module, lumen packages between 2,000 and 5,000 lm can be achieved with three driver wattages.

Thanks to low ripple current of +/- 5%, neither visible flickering nor stroboscopic effects will occur. The driver/module system ensures constant lumen output and uniform color temperature in lighting applications throughout the luminaire's service life.

The drivers achieve an efficiency of 88 %. Built-in protective functions such as temperature monitoring and temperature management, overload and overvoltage protection as well as short-circuit and no-load protection ensure safe operation of the luminaire modules. ■

Tridonic Adds Robust 200 W LED Drivers to Advanced Range

A new 200 W LED driver from the Advanced range - a high-performance component for high-bay industrial luminaires - has been added to Tridonic's industrial portfolio. The 0-10 V dimmable driver cannot fail to impress thanks to its universal input voltage range, IP 67 protection and high temperature resistance.

The independent LC 200 W 1050 mA UNV ADV IND constant current LED driver for luminaires featuring protection class 1 meets the requirements of IP 67 protection and is able to withstand both dry and damp and even wet environmental conditions at temperatures between -40 and 65°C, which makes it perfectly suited for industrial indoor and outdoor applications. Its maximum output power is 200 W, its maximum output current 1,050 mA. Thanks to the universal input voltage range from 110 to 277 V and certifications under CE, ENEC, CCC and UL, the driver is the ideal choice for world-wide use in various industrial applications, e.g. for illuminating production and sports facilities.

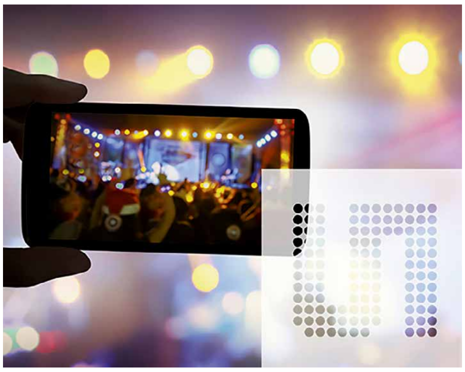
Tridonic's latest Advance Driver member, the LC 200 W 1050 mA UNV ADV IND, offers robust design for indoor and outdoor applications worldwide

In combination with Tridonic's high-lumen CLE or QLE high-bay modules, reliable system solutions can be created that combine high efficiency with low standby losses, high dielectric strength and a long service life. Hence, the driver boasts efficiency of more than 94%. Thanks to its dimensioning, just one module and just one driver are sufficient to produce a lumen output of up to 26,000 lm when combined with the CLE and QLE industrial modules. A long service life of up to 70,000 hours and an extended protection level of 2 kV against bursts and 6 kV against surges ensure high reliability and very little maintenance effort, which is especially called for in industrial environments where luminaires are difficult to access. In addition, functions such as over-temperature and overload protection as well as short circuit and no-load protection ensure safe operation.

The driver is accommodated in a rugged cast aluminum housing (240x68x37 mm) and even allows dimming of the lighting via the 0-10 V interface. It combines resistance against harsh environmental conditions required for industrial applications with many years of reliability and high energy savings. The manufacturer grants a guarantee period of 5 years. ■

ams Launches Smallest Available XYZ Tri-Stimulus True Color Sensor

ams, a leading worldwide supplier of high performance sensor solutions, released the TCS3430, the first XYZ tristimulus True Color sensor IC to be offered with a small footprint suitable for consumer devices such as notebooks, smartphones and tablets.



Miniature TCS3430 sensor IC uses advanced optical filter technology to produce illuminance and CCT measurements that closely match the response of the human eye

Advantages for users of mobile devices:

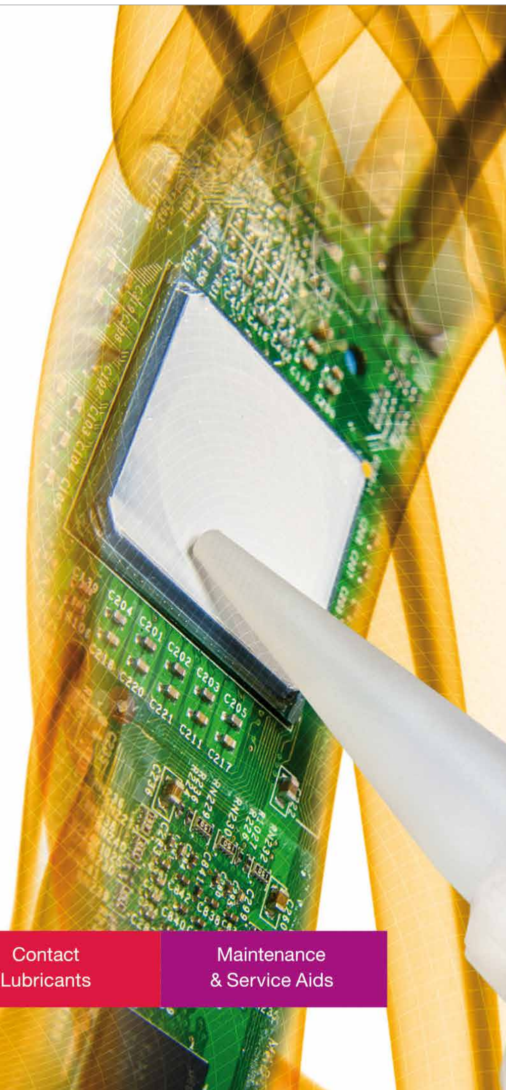
- Adapting the display color and brightness towards warm or cool white, based on the Correlated Color Temperature (CCT) level of the environment
- High quality display calibration to provide color balancing and vivid images based on the source input
- More realistic images and almost zero color distortion from the camera, rivaling the color balancing performance of professional-grade photography equipment

OEMs which move from RGB color sensors to the new cost effective TCS3430 will be able to achieve dramatic improvements in camera and display performance.

The TCS3430 benefits from proprietary ams technology for fabricating interferometric optical filters directly on the wafer. The ams interferometric filters can be made with the spectral characteristics of the XYZ spectral responsivity model of the human eye. In the TCS3430, the filters provide five channels: X, Y and Z channels and two infrared channels. The IR channels are used for advanced light source detection. The Y channel's response to the green portion of the visible light spectrum provides a measure of illuminance, enabling the TCS3430 to operate as an ambient light sensor as well as a color sensor.

The TCS3430 is supplied as a packaged IC measuring 2.41x1.75x1.00 mm. The aperture of the sensor needs to be covered by an achromatic diffuser. The TCS3430's high sensitivity and wide dynamic range mean that it can be mounted behind dark or transparent cover glass. It operates from a 1.8 V supply, and provides an I^2C interface to a host processor.

"The TCS3430 is the smallest available True Color sensor. It enables consumer products to drastically improve and manage their color and brightness performance, much more precise to the ambient light conditions and to the True Color of images", said Kevin Jensen, Senior Marketing Manager for Color Sensors at ams. "Consumers are becoming more and



more aware of the concept of color. Recent surveys confirm that consumers find it challenging to match items from their home to store or online products. The precise white point balancing of images does not only improve the quality of images for designers and professionals, but also assists general consumers to make decisions and reduce overall product returns", he added.

The TCS3430 is available for sampling. Unit pricing is $1.59 in an order quantity of 1,000 units. An eval kit for the TCS3430 is available.

Samsung Introduces Award-Winning Smart Sensor Module

Samsung Electronics Co., Ltd. has just completed development of a highly innovative, "Smart Sensor" Module (SSM) for use in the widest range of smart lighting applications. The new module was recently selected for the highest honor from the LIGHTFAIR International 2017 Innovation Awards in the category of "Controls: Components, Sensors, Interfaces and Software". LIGHTFAIR is the largest lighting conference in North America.

Samsung's SSM-U (left) and SSM-M (right)

The Smart Sensor Module is a key part of Samsung's Smart Lighting Platform (SLP). Samsung's SLP is a highly advanced end-to-end solution.

Main Features:

- A 2-channel programmable driver for white tuning, even without a controller
- An optional wired or wireless module that allows an ordinary driver to become smart via Bluetooth Low Energy mesh connectivity
- The new Smart Sensor Module, which can efficiently integrate Passive IR motion detection, RGB ambient light sensing, temperature management, humidity controls and advanced radar technology

"Our state-of-the-art smart sensor modules are an excellent example of Samsung's growing contribution to smart lighting and human-centric design, having been created to maximize the tremendous advantages and convenience of smart lighting in everyday life," said JaCoB Tarn, executive vice president, LED Business Team, Samsung Electronics. "With our introduction of these transformative solutions, we are making a clear statement on the importance of fully integrating smart lighting systems with human-centric lighting design."

Primary features of Samsung's SSM-U (ultra-wideband) series:

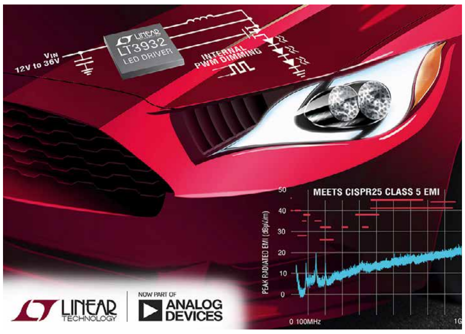
- Sensitivity can be adjusted by a smartphone
- Module can be positioned behind the diffuser for a more graceful design
- Simultaneously functions as a motion and occupancy sensor

The Samsung SSM series extends beyond the industry-transforming SSM-U, with a legacy version (SSM-M) that will enable existing luminaires to seamlessly accommodate a sensor network infrastructure in pre-installed systems, with minimal effort.

The new modules are available for evaluation now and Samsung will start mass production beginning Q3 2017.

36V, 2A Monolithic Silent Switcher Synchronous Step-Down LED Driver

Analog Devices, Inc., which recently acquired Linear Technology Corporation, announces the LT3932, a monolithic, synchronous, step-down DC/DC converter with internal 36 V, 2 A power switches and an internal PWM generator. Its fixed frequency, peak current mode control accurately regulates current within ±1.5% for strings of up to 2 A LEDs. Its integrated PWM generator offers a 128:1 dimming ratio. If dimming ratios of up to 5000:1 are required, the LT3932 and an external PWM generator can accommodate these applications.



Analog Devices' new LT3932 general purpose and automotive LED driver is a 36V, 2A LED driver with Silent Switcher® topology & internal PWM generator

The LT3932's 3.6 V to 36 V input voltage range is ideal for a wide variety of applications, including automotive, industrial and architectural lighting. The combination of its Silent Switcher® topology and spread spectrum frequency modulation minimizes EMI concerns. The LT3932 can drive up to eight 2 A white LEDs from a nominal 32 V input, delivering in excess of 50 watts.

Summary of Features: LT3932

- ±1.5% LED current regulation
- ±1.2% output voltage regulation
- 5000:1 PWM dimming at 100 Hz
- 128:1 Internal PWM dimming
- Spread spectrum frequency modulation
- Silent Switcher® Architecture for low EMI
- 3.6 V to 36 V input voltage range
- 0 V to 36 V LED string voltage
- 2 A, 36 V internal switches
- 200 kHz to 2 MHz with SYNC function
- 99.9% maximum duty cycle
- Analog or duty cycle LED current control
- Open/short LED protection & fault indication
- Accurate LED current sense with monitor output
- Programmable UVLO
- Thermally enhanced 28-lead (4×5 mm) QFN

The LT3932 can deliver efficiencies of 93% while switching at 2 MHz, eliminating the need for external heat sinking and offering a tiny, compact solution footprint. Internal open/short LED protection and fault indication offers added reliability. The LT3932's switching frequency is programmable from 200 kHz to 2 MHz or it can be synchronized to an external clock signal. Combined with a thermally enhanced 4x5 mm QFN package, the LT3932 offers a very compact high power LED driver solution. Other features include accurate LED current sense with a monitor output, 99.9% duty cycle operation and programmable UVLO.

The LT3932EUFD is available in a thermally enhanced 28-lead 4x5 mm QFN package. Three temperature grades are available, with operation from -40°C to 125°C (junction) for the extended, industrial grades and a high temperature grade of -40°C to 150°C. ■

Easy Color Measurement - Sphere Optics Presents New Spectraval 1511

Sphere Optics presents the new Spectraval 1511 from JETI, a very compact spectroradiometer for the visible wavelength range from 380 nm to 780 nm. The field of view of 2° can be marked by a red laser target to find the exact position of the measured spot. A further highlight is the mechanical shutter for dark signal compensation. The spectroradiometer is powered by an internal battery, but can also be operated via USB.

SphereOptics introduces the Spectraval 1511 spectroradiometer from JETI

Spectraval 1511 comes with a touchscreen and the measurements can be stored on an internal SD card. Therefore it could be used as a standalone unit without laptop or PC. The results for the color measurement are NIST traceable.

The measured data from Spectraval 1511 fulfill highest demands. The spectroradiometer delivers radiance, luminance, xy and u'v' coordinates, correlated color temperature, color rendering index and much more data. The results are easy-to-handle due to the clear software. Therefore a user specific computer interface allows to show the needed results at a first view.

The application of Spectraval 1511 is color measurement, for example for the verification of UV-lamps, fluorescence lamps, LEDs, or the calibration of monitors and projectors. ■

LumenFocus Announces New Heavy Duty High Bay

LumenFocus has added a new luminaire to its product line - the PBLHD heavy duty high bay. Part of the PBL family, the more durable HD is ideal for applications where the luminaire could be struck - such as gymnasiums and recreation centers. Wireguards are optional for added protection.

LumenFocus' new, heavy duty high bay is ideal for gymnasiums, recreation centers, factories and warehouses

Features Overview:

- Applications: Suitable for most commercial and institutional applications - ideal for gymnasiums, recreation centers, manufacturing, warehouse
- Lumen output: From 8,000 lm to 50,000 lm
- Max lumens per watt: 150
- Size options: Available in 4-foot and 2-foot
- Predicted (calculated) L70 lifetime: >200,000 hours
- Warranty: 5 year limited system warranty. 10-year extended warranty available on specific models
- Certifications: UL 1598 listed for US and Canada, suitable for damp locations. DesignLights Consortium qualified on specific configurations

In addition to the cable mounting kits offered on the PBL, the PBLHD can also be pendant- or surface- mounted. It comes in 4-foot or 2-foot versions.

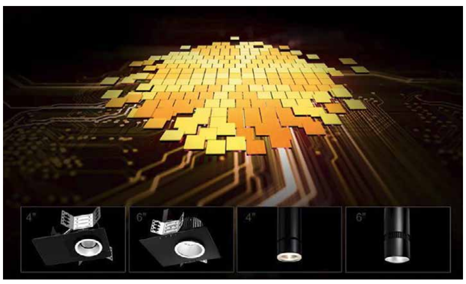
Several lumen packages are available, with a maximum output of around 50,000 lumens. The PBLHD can produce up to 150 lumens per watt. Dimming drivers (0-10V) are standard on most models. All boards and drivers are field-replaceable.

Frosted acrylic diffusers are optional to help minimize glare and improve aesthetics. Multiple control options are available - occupancy sensors, dimming sensors and photocells. Emergency packs and step-down transformers are also available. Conformal coating is an option for the LED boards.

The PBLHD is manufactured in the USA. Specific configurations are DesignLights Consortium qualified. The PBLHD is UL 1598 listed for the US and Canada, and is suitable for damp locations. ■

Tunable White Gets a Practical Tune-Up with Meteor's New ColorFlip™

Meteor reveals the latest technological advance, an innovative ColorFlip™ tunable white light engine. The ColorFlip™ has the highest light output in the market at up to 10,000 lumens throughout 2700-6500 K. This practical tunable white solution provides flexible lighting for multiple occasions, without sacrificing output or going over project budget.



Meteor's new ColorFlip™ is a proprietary tunable white solution at affordable costs

Utilizing the latest flip chip LED technology, the ColorFlip™ delivers superior heat management as well as lowest thermal resistance; it results in higher performance from all fixture components. Meteor's ColorFlip™ technology allows for 70% more heat dissipation and lumen output than other LED technologies.

Meteor's proprietary control unit and driver technology allows the ColorFlip™ to bring compatibility with every existing control system, eliminating the need for expensive, standalone control systems. As with all of Meteor's fixtures, the ColorFlip™ employs VX Driver that eliminates flickering when using video recording devices. With the ColorFlip™ lighting designers takes total control of the color temperature even after lighting fixtures are installed. Color temperature no longer needs to be decided during planning stage, field adjustable CCT is possible with Meteor's newest development - ColorFlip™.

While traditional tunable white solutions require doubling the number of LEDs to equal the output of single-color lights, ColorFlip™'s unique design and proprietary control board delivers maximum lumen output during color tuning. At only 20% more per fixture, there's no doubling the budget to meet output requirements. From large-scale projects like convention centers, to multipurpose rooms in community centers, Meteor's ColorFlip™ technology answers to all color tuning requests.

Meteor's new ColorFlip™ tunable white solution will apply to 4" and 6" cylinder and recessed downlight in September 2017. ■

Lumitec Pinnacle - Style and Performance in a Small Package

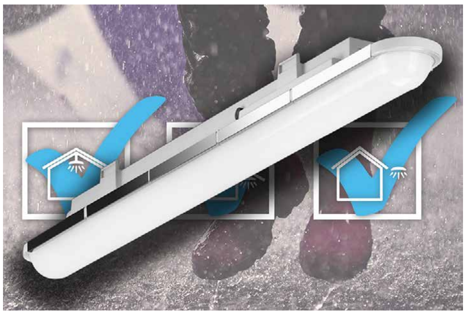
Lumitec, a leading designer and manufacturer of extreme environment LED lighting solutions, officially announces the launch of their new Pinnacle LED Flood Light.

Lumitec's Pinnacle is a compact, radially symmetrical marine spot/flood light

The Lumitec name has become synonymous with high quality deck and flood lighting. Pinnacle offers a 1,000+ lumens output similar to our wildly successful Caprera line of marine flood lights. But Pinnacle's radially symmetrical spot/flood optical design stays tighter and punches farther. With a small profile and versatile mounting bracket Pinnacle is well suited to light the way forward on land or at sea. From off-roader light bars to wakeboard towers Pinnacle is the perfect solution when high performance and good looks count. ■

Zaleda Evol II - Premium Weatherproof Luminaire for Indoors and Outdoors

OEM Systems Group's new LED weatherproof luminaire Zaleda Evol II meets all specifications for a highly durable premium solution, both indoors and outdoors. This is the very first indoor luminaire just as suitable for outdoor applications - even without roofing; highly robust and efficient, with quality of light for increased demands and flexible, versatile use.



OEM Systems Group's new ZALEDA EVOL II can be used in a wide range of environments, from cold to hot, providing high efficiency and long lifetime

Slender design with high resistance:
The premium quality of ZALEDA EVOL II becomes apparent at the first glance: the high quality luminaire body made of die-cast aluminum brings together good looks with high resistance to a wide range of external factors, while also contributing to highly effective thermal management. Impact-resistant UV-stabilized polycarbonate or PMMA ensures robustness and durability, as do the mounting clips of rust-free steel.

The LED weatherproof luminaire also features a modern design and compact dimensions of 1047 x 105 x 95 mm (LxHxW).

The luminaire is resistant to low temperatures, heat, humidity, dust, knocks and impact and complies to protection rating IP66 and IK08. It can be used in a wide -30°C to +45°C temperature range. As a result, it is the universal solution for a variety of applications ranging from cold stores and production halls to car parks and outdoor areas.

Energy-efficient light:
In common with its attractive and highly resistant outer, the luminaire also meets high demands in terms of quality of light: ZALEDA EVOL II generates uniform, glare-free and especially energy-efficient light. State-of-the-art electronic components from BAG bring together high performance values with reliability and efficiency. The result is constantly high quality of light with an above-average life time of 85,000 hours. Thanks to energy efficiency of 139 lm/W and low installation and

maintenance complexity, the luminaire in use achieves low overall operating costs. The quality of light also wins over - with a length of just 1 meter the luminaire achieves the same effect as conventional 1.50 meter-length weatherproof luminaires.

The HF sensor version improves the energy balance even further. Presence- and daylight sensors automatically switch off the luminaire or dim it to a pre-set level. The result: further energy savings of up to 35%. Sensor control also increases the lighting comfort - e.g. in the form of "running light" that tracks people on their way through buildings. ■

Shat-R-Shield® Launches Ironclad™ LED Vapor Tight High Bay Fixture

Shat-R-Shield, Inc. announces the new Ironclad™ LED Vapor Tight High Bay luminaire as a retrofit for fluorescent fixtures commonly installed in applications exposed to moisture, dust and other harsh elements that require frequent wash-down.

Shat-R-Shield's new Ironclad™ LED Vapor Tight high bay luminaire is a retrofit for fluorescent fixtures

With industry leading lumen outputs of 22,000 and 33,000, this high efficiency NSF-rated, non-metallic LED solution replaces a six lamp T8 or six lamp T5 fixture and is ideal for general illumination mounted in ceiling heights of 20-30 feet.

Shat-R-Shield's Ironclad™ VTHB is constructed of fiberglass reinforced polycarbonate with a seamless gasket seal and stainless steel components for optimal chemical and impact resistance. Its rounded edges allow for easy water shed and durability against high-pressure hose down up to 1500 PSI. The tethered lens is available in clear or frosted for uniform, glare-free illumination.

Offered in 158 watt (22,120 lumens) and 236 watt (32,860 lumens) models, the Ironclad™ VTHB is available with color temperatures of 4000 K or 5000 K, voltages of 120-277 V or 347-480 V, and an option for 90 minutes of battery backup. It comes standard with 0-10 V dimming, has a CRI of 80, L70 of >72,000 hours and an operating temperature of -40°C to 50°C backed by a five-year warranty.

The VTHB boasts an impressive certification base consisting of NSF, DLC, cUL, UL Wet Location and UL1598 with ratings including IP65, IP66, IP67, NEMA 4X, NEMA 5 and 5VA flammability rating. The ruggedness of the luminaire paired with unmatched light performance makes it the quintessential solution for food and beverage processing, industrial facilities, tunnels, parking garages, cold storage, wastewater treatment plants and more. ■

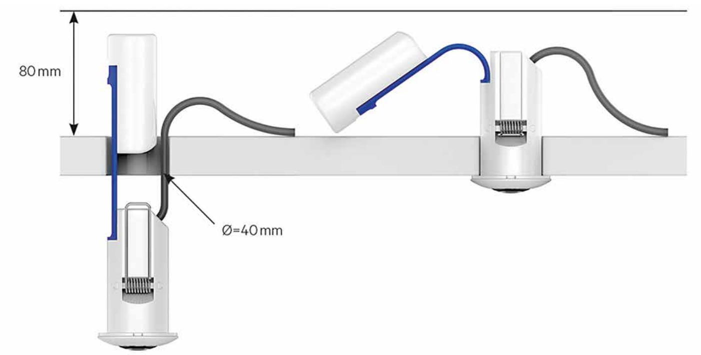
Tridonic Presents Out of the Box Solution for Emergency Lighting

Tridonic has developed an all-in-one, "out of the box" solution for emergency lighting. The EM ready2apply recessed downlight now being launched on the market includes all components for emergency lighting in one single box: light source, driver, battery, optic. The well-thought-out installation concept allows for quick and easy installation.

EM ready2apply at a glance:

- Maintained and non-maintained versions
- BASIC, SELFTEST and DALI (PRO)
- 3 interchangeable lenses with push-click-connection (anti-panic, escape route and spot)
- Impressive spacings thanks to lens technology
- Battery with an 8-year design life and 3-year guarantee
- 5-year guarantee on electronic components

Chris Slattery, Global Product Manager for Emergency Lighting at Tridonic, explains: "Our aim was to design a compact and easy-to-install product that can be inserted into the ceiling void through a minimal cut-out. It had to exceed all lifetime and safety requirements and offer interchangeable lenses." The result is the EM ready2apply engine, a stand-alone emergency luminaire that was subjected to rigorous testing procedures and complies with the most stringent safety and reliability criteria.



Tridonic's new EM ready2apply emergency lighting system is based on lithium-iron phosphate battery technology and it is easy to install

A major challenge was to find a battery that would be small enough but also pack enough power for all possible applications. The current NiCd and NiMH technology did not allow for delivery of the necessary performance in the size required. After extensive research and testing, Tridonic settled on a lithium-iron phosphate ($LiFePO_4$) battery that keeps the maintenance costs low thanks to its service life of eight years. The low standby loss ensures minimum energy consumption. Thanks to the specifically developed push-click-connection, the battery can be inserted quickly.

The entire engine is also easy to install. The installation concept even uses the packaging as convenient installation aid. A mounting depth of a few centimeters is enough to accommodate the space-saving housing with integrated driver.

The new emergency lighting downlight provides a suitable optic for every area of application. In total, three interchangeable optics for anti-panic, escape-route and spot lighting are available. They can easily be exchanged at a click.

The three models Basic, Selftest and Pro can be combined with one, two or three hours of operation (two hours in case of Pro). Moreover, the engine is optionally suited for maintained or non-maintained operation. ■

Concrete and LEDs - Sattler's New AVVENI is a “Dance of Polarities”

Sattler's new AVVENI variant: Table and floor lamp with a cylindrical concrete stand unlocks even more possible uses in your home. The flexible Avveni lighting system holds in itself the “potential for further variants” - so the refreshing, yet factual comment by the Focus Open Design Award jurors on the modular Avveni luminaire and its numerous and conceptually designed variations. In collaboration with code2design, Michael Schmidt, a “variant” has been created by Ulrich Sattler in form of a table and floor lamp named Avveni Concrete.

Avveni Concrete features a moveable light head resting on an unostentatious, cylindrical concrete stand. The light head retains its lightness and flexibility via the magnetic ball joint, contrasted by the sturdy base made of fair-faced concrete - a surprising polarity between materiality and display. Concrete has become a trendy material for stylish interiors and gives the Avveni luminaire a new impetus in the domain of lighting.

The light head is available either as a flood disk in prismatic optics or as a single spot light with a 9° illumination characteristic. The beam angle can be changed to 25 °, 36° or 60 ° by means of a snap system

The Avveni Concrete is characterized by a harmonious polarity between the optically appealing structure of the concrete with all its little cavities and bubbles and the well-proportioned surface of the light head, which is available in two colors, brushed and anodized or in polished aluminum. A lot of tinkering was required by the Sattler designers in order to retain the original character of the concrete for the surface of the cylindrical base - a visible roughness, yet pronounced refined aesthetics have been achieved. The distinct and defined edges create an elegant and smooth transition to the other Avveni components.

The design of the magnetic ball joint was inspired by the mobility of the human shoulder. It connects the lamp base with the light head, which can be exchanged at any time and rotated by 360° as well as tilted by 180°. This extraordinary flexibility is visually balanced by the simple cylindrical shape of the stand.

Balance between stability and lightness: A small slit in the foot hides the cable duct and also elegantly reduces the sturdiness of the base. The light head, seemingly dancing on the grey stand, is customarily available as a prism disk for general lighting or as an individual spot light with different beam angles. A sophisticated add-on inspires different uses: The lamp base contains a holder, which instantly turns the Avveni Concrete into a wall lamp.

Award-winning luminaire product family: In 2016 the Avveni lighting system received the highest award in the category of lighting by the Design Center Baden-Württemberg. An independent jury emphasized that the modular design offered the “potentiality for further variants by the use of identically clear, yet sculptural design language”. By creating the Avveni Concrete luminaire, both Ulrich Sattler and Michael Schmidt (code2design) have demonstrated yet another use of the lighting system and its realization with the usual perfection in every detail. Conceptualized as a product family, for 2017, the Avveni lighting system has also received the iF Design Award, the Stevie Award as well as the German Design Award. Furthermore, the Avveni Concrete was honored with the DARC award Decorative in the “Floor Lamp” category.

MaxLite Presents Flicker-Free LED T8 Lamps

Providing superior light quality and performance, MaxLite introduces flicker-free LED T8 Lamps as the long-lasting, energy-efficient replacement for fluorescent tubes in offices, classrooms and other commercial and educational applications.

MaxLite's new Flicker-Free LED T8 lamps made to provide high-quality lighting for commercial and educational environments

The lamps deliver smooth and flicker-free light without the distractions, eyestrain and headaches commonly associated with fluorescent light sources. Designed to retrofit linear fixtures with standard G13 (medium bi-pin) sockets using a simple ballast bypass, the UL Type B lamps operate with a dedicated internal driver for optimal performance and reliability. The lamps are DesignLights Consortium (DLC) listed and qualify for nationwide utility rebates, enabling school districts, universities and facility managers to reach a quick return on investment.

“Quality of light plays an essential role in classroom and workplace productivity, yet most schools and businesses have inefficient systems that drain energy and negatively affect morale,” noted MaxLite Product Manager Alex Truong. “Replacing fluorescent lighting with LED is the smart and simple way to reduce operational expenses, improve sustainability and create more engaging learning and working environments.”

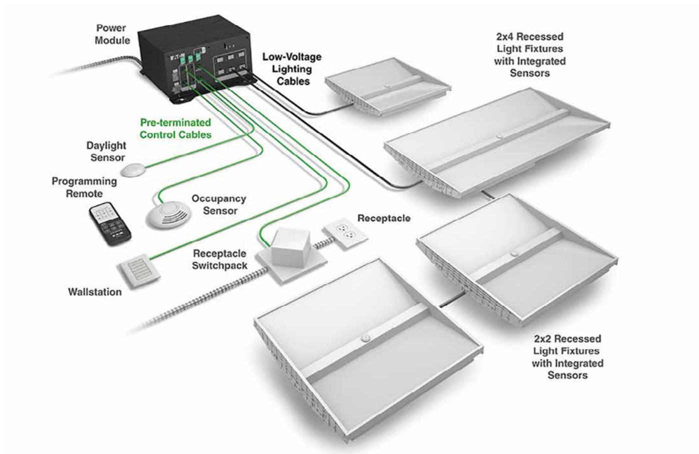
MaxLite offers the flicker-free models in outputs of 1,800 and 2,200 lumens, with a choice of 3500 K, 4000 K and 5000 K color temperatures. Constructed of coated glass, the 4-foot-long lamps are tested to National Sanitation Foundation (NSF) standards and carry the ETL Sanitation Mark, making the lamps an ideal choice for lighting food service areas. In addition, the lamps comply with flicker test methods of Joint Appendix 10 (JA10) of the Title 24 building code requirements in the State of California.

MaxLite Flicker-Free LED T8 Lamps consume up to 50 percent less energy than fluorescent tubes and have a long, maintenance-free lifetime of 50,000 hours. The lamps are supported with a five-year limited warranty and lifetime product support.

Eaton Low-Voltage Solution for LED Lighting, Power and Controls

Power management company Eaton offers the Distributed Low Voltage Power (DLVP) system, a flexible and electrically efficient low-voltage system combining power, LED lighting and controls into one simple, energy code compliant, project solution by blending the benefits of both alternating current (AC) and direct current (DC) power distribution. The easily configured “plug-and-play” system reduces installation labor by up to 40 percent with a total installed system cost savings of up to 20 percent.

The energy-efficient, commissioning DLVP solution utilizes AC power for transmission and DC power for connectivity, offering a complete low-voltage, simple solution for applications with repeated spaces and matching configurations including schools, private and open commercial offices, conference rooms and healthcare facilities such as doctor’s offices, urgent care and rehabilitation centers. The light-emitting diode system was recently installed in the Cincinnati, Ohio-based offices of US Greentech, a company focused on the development and distribution of progressive synthetic turf infill for the sports field industry.



Eaton's new, simple low-voltage solution for power, LED lighting and controls saves up to 40 percent on installation labor hours

“Whether managing a single room or entire facility, customers and installers want a safe, cost-conscious, easy-to-configure system that simplifies code compliance,” said Quentin Mecklenborg, owner, Brooks and Sons Remodeling, who installed US Greentech’s DLVP system. “It took one person less than a day to install a 2,000 square foot space with lighting, from running the wire to the power module and connecting all the fixtures to working order versus traditional wiring, which would have taken two electricians over a day to wire the same amount of fixtures.”

“The out-of-the-box functionality of the DLVP system provides design-build contractors, installers and owners an LED lighting and controls solution that offers fast, simple installation with reduced wiring materials and minimal complexity,” said Chris Andrews, product manager, Eaton’s Lighting Division. “The sustainable solution allows customers the ability to control and program different lighting products based on occupancy and daylighting. Our system provides energy code compliant lighting, receptacle and emergency controls capabilities without commissioning.”

The DLVP system components include a power module, available in 300 and 600 W; traditional lighting control options including occupancy and daylight sensors; zone and scene wall stations that offer out-of-the-box control; and receptacle control switch packs to control receptacle plug loads.

The DLVP system includes hand-held programming and personal remotes. The programming remote sets sensor hold times and sensitivity, daylight gains by zone, sensor range and assigns fixtures with integrated sensors to control zones. The personal remote provides the user the ability to individually control zones and create scenes to customize their lighting environments.

The system is compatible with models representing Eaton’s most popular lighting product lines including Metalux, Corelite, Neo-Ray, Portfolio and Halo Commercial. ■

Feit Electric Announces Availability of IntelliBulb™ LED Lighting Solutions

Feit Electric, a leading global lighting manufacturer and pioneer in energy efficient lighting, today announced the availability of its IntelliBulb™ LED energy-saving lighting solutions with effortless customization and problem-solving capabilities.

Feit Electric's five different IntelliBulb lighting solutions

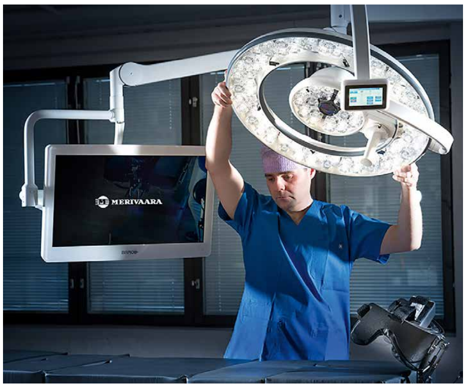
Main Features:

- Dusk to Dawn: Built-in light sensor automatically turns bulb on at night and off during the day. Perfect for outdoor light fixtures or any location you want a care-free way to keep well-lit at night. The 60-watt equivalent A-19 bulbs are available in 2700 K and 5000 K
- Motion Activated: Motion activated A-19 light bulbs turn on when triggered from up to 19 feet away. The 180-degree microwave sensor detects movement even if the bulb is used in glass fixtures or a table lamp with a shade. Install this bulb in a garage, basement, closet light fixture or anywhere you need a handy hands-free way to light up a space as you walk by
- Switch to Dim: Choose from three brightness settings – 100%, 60% and 10% – using a standard light switch. The A-19 and BR-30 light bulbs allow users to adjust the light intensity without the additional expense or effort of installing a dimmer switch
- ColorChoice: Get three color temperature choices – warm white, cool white and daylight – in one bulb. Choose the desired color temperature using a standard wall light switch or pre-select using the switch on the bulb. Available in A-19 and BR-30, the bulbs can also be used with dimmers
- Battery Backup: Make frantic situations less frantic with up to three hours of reliable emergency battery backup lighting. If the power goes out, the bulb will stay lit. It's rechargeable, fits a standard light bulb fixture and is ready whenever a need occurs. The bulb can also be used in enclosed fixtures and damp locations

With IntelliBulb solutions, all the intelligence is built into the bulb so there is no need for special smart home hardware, mobile apps or dimmers to optimize lighting for a particular environment, situation or task. Lighting can be controlled with motion or a light switch you already have, providing the benefits of a smarter home without costly installations or hassle. IntelliBulb light bulbs also offer all the energy saving advantages of the latest LED technology and last up to 15,000 hours or 13.7 years at three hours per day. ■

New Merivaara Q-Flow Surgical Light to Reduce the Risk of Infections

The Merivaara Q-Flow™ surgical light improves the working environment in operating rooms, and also offers a new way to reduce the risk of infections. Q-Flow is a major step forward from traditional operating room lights. Designed and manufactured in Finland, Q-Flow was developed to fulfill the needs of the modern surgical team. It offers improvements on many standard features in the industry as well as radical innovations.



The design improves laminar air flow to better maintain sterile conditions and, hence, reduces the risk of infection

"I believe this is one of the best operating theatre lights in the world," says CEO Markku Aherto. "We are very excited about this excellent product."

The light achieves superb color rendering, particularly in red and skin shades, which makes the product perfect for a variety of surgical procedures such as internal or plastic surgery. The Q-Flow gives a very deep column of light and dynamic obstacle compensation, so if the surgeon bends over his or her patient, sensors brighten other LEDs to reduce shadows.

Moreover, the light has sterile and intuitive controls. The Q-Flow displays simple user instructions on the operating table so the surgeon does not have to look up.

"We had surgeons, anesthesiologists and nurses give us their input as we developed the Q-Flow," Aherto continues. "They are very enthusiastic about the final result."

One of the most ground-breaking features is the way it improves hygienic conditions. Standard operating room lights create turbulence intensity, acting like an aircraft wing to pull particulates in the air right over the patient. Merivaara's designers shaped the Q-Flow as a series of concentric circles with open spaces in between. This improves laminar air flow so sterile conditions are maintained and the risk of infection is reduced. The standard turbulence intensity should be below 37.5% but the Q-Flow boasts 15.9% according to the DIN 1946-4:2008 standard.

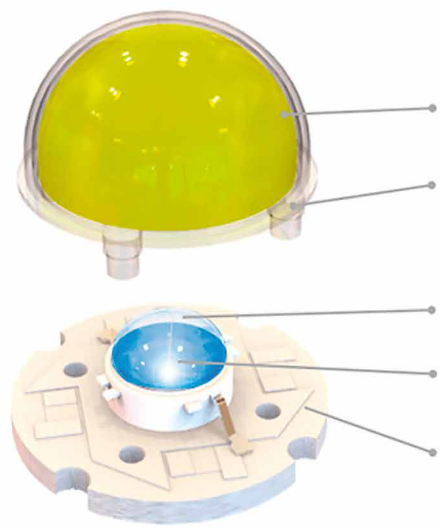
The Q-Flow surgical light has already won two prestigious design awards: the Red Dot Award for Product Design in 2017 and the Fennia Prize Grand Prix 2017 for its outstanding design.

The Q-Flow is a part of the Merivaara Fluent™ concept, which enhances the usability of operating rooms. This includes an intuitive user interface which works across a variety of devices, such as Q-Flow, operating tables and an integrated management system. Often a single operating room may have equipment with different user interfaces. With Merivaara Fluent, each device can have the same user interface, allowing the medical staff to concentrate on the patient instead of learning how to use the devices.

"All the Q-Flow's design and technology is Finnish," concludes Aherto. "Finnish health-tech has a very good reputation around the globe. I am proud that we can offer something to the world which contributes to Finland's great reputation." ■

1000 Hour QD LED Milestone Surpassed by Quantum Materials

Leading American cadmium-free Quantum Dot manufacturer, Quantum Materials Corp., announced successfully surpassing the 1000 hour continuous on-time durability test for the Company's cadmium-free quantum dots in a remote light emitting diode (LED) application. The testing has been conducted with red and green quantum dots encapsulated in resin and mounted to blue emitting LED's (see diagram below), which are similar to the type of LED's used in standard LCD display back light units (BLU).



The DUT for the reliability test is a remote QD mid power LED consisting of the components shown on the image

The successful implementation of quantum dots with LED's has been slow to progress primarily due to the challenge of achieving the requisite reliability and durability to survive the heat generation inside the LED package without suffering thermal quenching and rapid performance deterioration. The QD-LEDs were under continuous power at 2.5 Volts DC at 70 mA and were measured initially, incrementally and at the 1000 hour mark with no measurable degradation of intensity, peak emission or FWHM, which is the measure for color purity. The QD-LED packaged units will continue to be under power and measurements of key performance criteria taken through and beyond the 3000 hour test protocol.

Quantum Materials Corp President and CEO Stephen Squires said, "Passing the 1000 hour continuous on time milestone is a major achievement in proving our quantum dot and encapsulation technologies. They are the basis for the next generation of quantum dot solutions to improve the color rendering capability of flat panel displays - which is moving QD's from the front of the LCD panel to the actual surface of LED's."

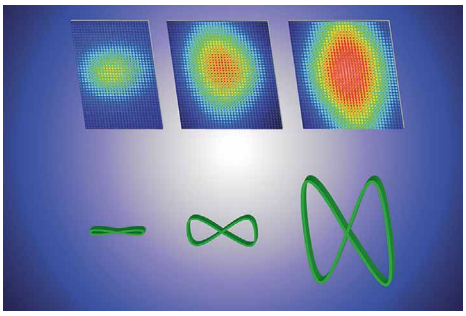
Semiconductor quantum dots have attracted tremendous attention for their unique characteristics for solid state lighting and displays. The pure and tunable spectra of QDs make it possible to simultaneously achieve excellent color rendering properties and high luminous efficiency when combining colloidal QD's with light emitting diodes (LED's) or Micro LEDs.

"Achieving 1000 hours of continuous illumination with zero degradation is an extraordinary accomplishment that can move the reality of true QD-LED technology one step closer to reality. It is even more so when you consider all our materials, regardless of whether they are prototype or production, are produced using our proprietary continuous flow production process enabling seamless scale-up to high volume production," said Toshi Ando, Quantum Materials Corp Senior Director of Business Development.

Mr. Squires concluded that "While we expect QD-infused film to be the preferred display solution for the next several years, the high heat durability and stability of our QD materials puts us in a strong position to enable the industry to make this transition to QD-LED on-chip solutions when that time comes."

Brightest Laser Sparks New Behavior in Light

Physicists from the University of Nebraska-Lincoln are seeing an everyday phenomenon in a new light. y focusing laser light to a brightness 1 billion times greater than the surface of the sun - the brightest light ever produced on Earth - the physicists have observed changes in a vision-enabling interaction between light and matter.



A rendering of how changes in an electron's motion (bottom) alter the scattering of light (top), as measured in a new experiment that scattered more than 500 photons of light from a single electron

Those changes yielded unique X-ray pulses with the potential to generate extremely high-resolution imagery useful for medical, engineering, scientific and security purposes. The team's findings, detailed June 26 in the journal Nature Photonics, should also help inform future experiments involving high-intensity lasers. Donald Umstadter and colleagues at the university's Extreme Light Laboratory fired their Diocles Laser at a beam of electrons to measure how the laser's photons - considered both particles and waves of light - scattered from a single electron after striking it.

Under typical conditions, as when light from a bulb or the sun strikes a surface, that scattering phenomenon makes vision possible. But an electron - the negatively charged particle present in matter-forming atoms - normally scatters just one photon of light at a time. And the average electron rarely enjoys even that privilege, getting struck only once every four months or so.

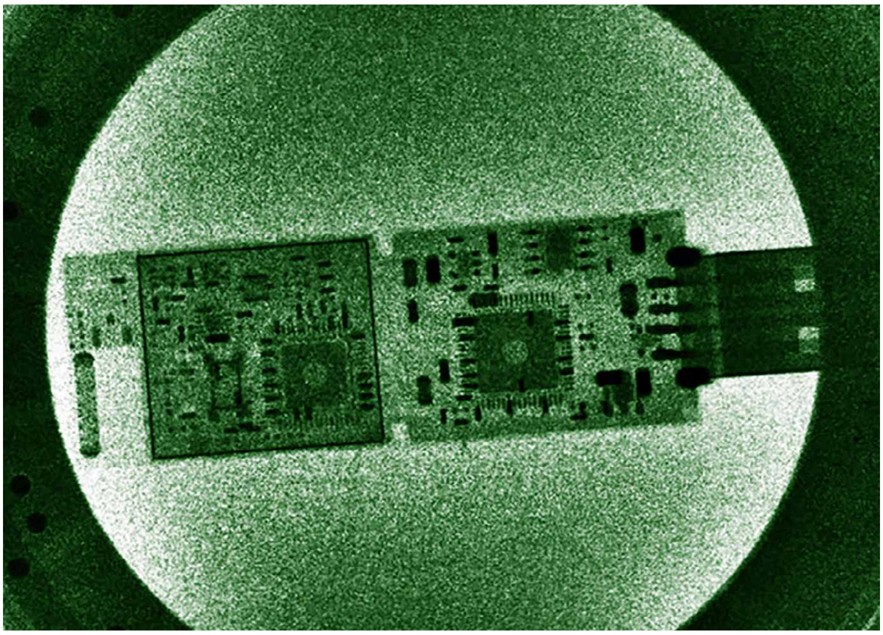
Though previous laser-based experiments had scattered a few photons from the same electron, Umstadter's team managed to scatter nearly 1,000 photons at a time. At the ultra-high intensities produced by the laser, both the photons and electron behaved much differently than usual.

"When we have this unimaginably bright light, it turns out that the scattering - this fundamental thing that makes everything visible - fundamentally changes in nature," said Umstadter, the Leland and Dorothy Olson Professor of Physics and Astronomy.

A photon from standard light will typically scatter at the same angle and energy it featured before striking the electron, regardless of how bright its light might be. Yet Umstadter's team found that, above a certain threshold, the laser's brightness altered the angle, shape and wavelength of that scattered light.

"So it's as if things appear differently as you turn up the brightness of the light, which is not something you normally would experience," Umstadter said. "(An object) normally becomes brighter, but otherwise, it looks just like it did with a lower light level. But here, the light is changing (the object's) appearance. The light's coming off at different angles, with different colors, depending on how bright it is."

That phenomenon stemmed partly from a change in the electron, which abandoned its usual up-and-down motion in favor of a figure 8 flight pattern. As it would under normal conditions, the electron also ejected its own photon, which was jarred loose by the energy of the incoming photons. But the researchers found that the ejected photon absorbed the collective energy of all the



Extreme Light Laboratory | University of Nebraska-Lincoln - Using a laser focused to the brightest intensity yet recorded, physicists at the Extreme Light Laboratory produced unique X-ray pulses with greater energy than their conventional counterparts. The team demonstrated these X-rays by imaging the circuitry of a USB drive

scattered photons, granting it the energy and wavelength of an X-ray.

According to Umstadter, the unique properties of that X-ray might be applied in multiple ways. Its extreme but narrow range of energy, combined with its extraordinarily short duration, could help generate three-dimensional images on the nanoscopic scale while reducing the dose necessary to produce them.

Those qualities might qualify it to hunt for tumors or microfractures that elude conventional X-rays, map the molecular landscapes of nanoscopic materials now finding their way into semiconductor technology, or detect increasingly sophisticated threats at security checkpoints. Atomic and molecular physicists could also employ the X-ray as a form of ultrafast camera to capture snapshots of electron motion or chemical reactions.

"Since our X-ray device fits in a hospital or factory, it can be more widely used than conventional alternatives," explained lead author Wenchao Yan, postdoctoral researcher in physics and astronomy.

Umstadter, Yan and their colleagues also expressed excitement for the scientific implications of their experiment.
By establishing a relationship between the laser's brightness and the properties of its scattered light, the team confirmed a recently proposed method for measuring a laser's peak intensity.
The study also supported several longstanding hypotheses that technological limitations had kept physicists from directly testing.

"For many years, there were many theories that had never been tested in the lab, because we never had a bright-enough light source to actually do the experiment," Umstadter stated. "There were various predictions for what would happen, and we have confirmed some of those predictions."

"It's all part of what we call electrodynamics. There are textbooks on classical electrodynamics that all physicists learn. So this, in a sense, was really a textbook experiment."

Umstadter and Yan authored the study with Sudeep Banerjee and Shouyuan Chen, research associate professors of physics and astronomy; Grigory Golovin and Cheng Liu, senior research associates in physics and astronomy; Ping Zhang, Baozhen Zhao and Jun Zhang, postdoctoral researchers in physics and astronomy; Colton Fruhling and Daniel Haden, doctoral students in physics and astronomy; along with Min Chen and Ji Luo of Shanghai Jiao Tong University. ■

Luger Research Creates an Active Network to Secure the Future of Innovation in Lighting

Luger Research establishes the first scientific lighting partnership network for research experts and leaders in the lighting industry. The scientific partnership has been created to form an active network that will strengthen and build the connections between universities, research laboratories and industry. The scientific partnership's mission is to enable and secure the continued development of innovation in lighting technology.

Strategic alliances are important, and in the world of research they are crucial for the continued development of future innovations. Likewise, industry requires the latest insights and findings from the research organizations to make sure their products and solutions are the very best they can be. By building these scientific partnerships, Luger Research will drive lighting innovation towards a more sustainable and better future.

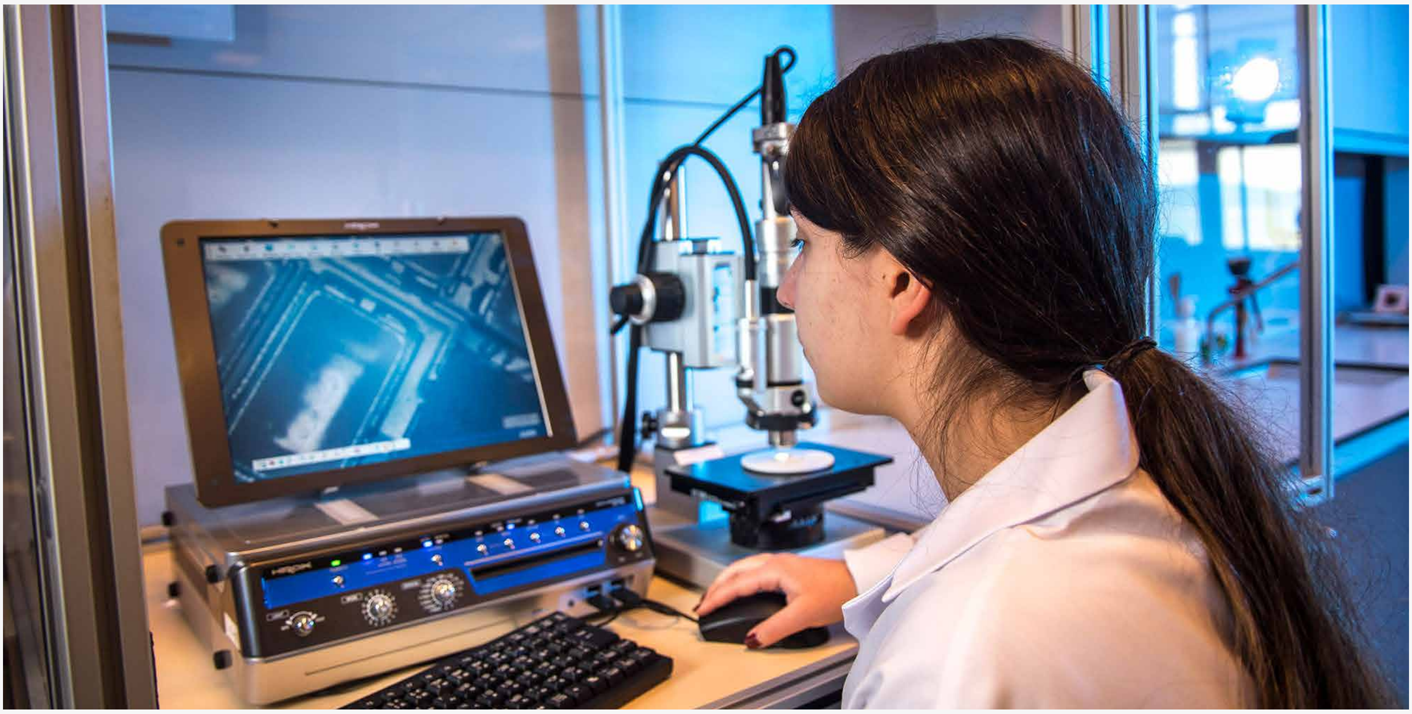
Joining Luger Research in this venture are some of Europe's leading universities and research laboratories. These scientific partners will also make up the jury and expert panel assessing this year's prestigious LpS Scientific Award.

The first meeting of the scientific partners and industry leaders will take place at the LpS 2017, in a specialist workshop on September 28. This workshop has been tailored to encourage and build new connections between scientific partners and potential applicators of their know-how.

To make sure the connections that are formed are best suited to every participant in the workshop, the scientific partners will be divided into four technology expertise fields. These are LED and OLED, driver, thermal management and reliability, optics and light quality, and smart lighting and IoT.

"We want to draw together mutually beneficial partnerships between lighting research and the lighting industry. Luger Research and all of our publications, media channels and events, will operate as a platform that will enable the clear and open sharing of information into the development of lighting technology. It will also act as the facilitator for, what we intend to be, long lasting and mutually beneficial partnerships between research and industry. We want to help bring to life these new innovations that can benefit advances in wellbeing and improve sustainability for us all and for the future." Siegfried Luger, CEO at Luger Research

The scientific lighting partnership is currently centered on Europe but the long term ambitions are that it will evolve in the coming years to become the world's leading lighting technology network. ■



Scientific Partner	Specialism & Short Description
Energy Efficient Electronics and Lighting Technologies Research, Demonstration and Education Centre (EVATEG) *Istanbul, Turkey*	Thermal Management and Optical Technologies EVATEG Center develops thermal technologies for electronics, solid state lighting and display technologies and optical technologies for solid state lighting applications. EVATEG's capability includes both theoretical studies and experimental validation with prototypes for specific applications. EVATEG is open to license technologies through Ozyegin University Technology Transfer Office and spin off companies in the technology eco-system.
Joanneum Research Forschungsgesellschaft mbH. Materials - Institute for Surface Technologies and Photonics *Weiz, Austria*	Optics: Design and Manufacture and Photovoltaics The research topic Optics: Design and Manufacture brings together three separate disciplines: optical simulation, the manufacture of optical components and the optical characterization of these components. The aim here is to incorporate aspects relating to optics manufacturing and the overall structure during the optical simulation in a sort of virtual prototyping. The area of photovoltaics deals with the continuing development and the increase in efficiency of established (silicon- or CIGS-based) and future (e.g. OPV) photovoltaic technologies through use.
Steinbeis Transferzentrum Beleuchtungsoptik und Lichttechnik *Furtwangen, Germany*	Illumination Optics and Lighting Technologies and Colorimetry Key research areas regarding illumination optics include: Luminaires development and optimization by means of optomechanical simulations, Development of backlighting systems for display applications and hollow wave guides, spectroscopic analysis of lighting sources. With regards to lighting technologies and colorimetry the key area is optical simulation and measurements of the reflection/absorption properties of human tissues.
Holst Centre, TNO *Eindhoven, The Netherlands*	Flexible Electronics and Flexible OLED Holst Centre is an independent R&D centre that develops technologies for wireless autonomous sensor technologies and flexible electronics, in an open innovation setting and in dedicated research trajectories. A key feature of Holst Centre is its partnership model with industry and academia based around roadmaps and programs. It is this kind of cross-fertilization that enables Holst Centre to tune its scientific strategy to industrial needs.
CSEM SA *Muttenz, Switzerland*	Photonics & Printing for SSL (including Micro- & Nano- Optics and Photonics, Sensing and Security and Large Area and Flexible Systems) and Vision and Optical Sensing Systems for SSL CSEM has experience in the areas of micro/nano optics and photonics as well as printed electronics. Over the last decade, CSEM has developed technologies that allow the fabrication of optical and photonic subwavelength structures with periods from below 200 nm up to several microns, and has the capability to design, fabricate and characterize micro/nano diffractive structures and thin layers.
The University of Edinburgh, Institute for Digital Communication *Edinburgh, UK*	Visible Light Communications (LiFi) The research tackles both theoretical and fundamental communications problems as well as more practical issues of implementing and improving communications systems. The work addresses a wide range of technologies including wireline, radio frequency and optical communications systems, as well as improving communications interfaces. Recent in depth work has focused on transmitting data at high speed via visible light.
University of Padova, Department of Information Engineering *Padova, Italy*	Characterization, Reliability and Simulation of Compound Semiconductor Devices (LEDs, Laser diodes, HEMTs) and Solar Cells
KTH. Sweden and SELITERA AB *Stockholm, Sweden*	Semantic and Cognitive Light SLC- provides machine understanding and learning of an illuminated scene in order to transform conventional agnostic lighting into dynamic, intelligent lighting by digitally altering the quality, quantity and informational capacity of light based on awareness of the individual, his/her current context, the task at hand, location and mobility.

TECHNICAL REGULATORY COMPLIANCE UPDATE

Segment	Product	Standard (Certification)	Region	Technical Regulatory Compliance Information
Regulations	Luminaires	UL8800	US	In May 2017 the 'UL 8800 Outline of Investigation for Horticultural Lighting Equipment' was published. This is a summary of applicable safety requirements for horticultural lighting equipment referencing the different applicable standards and additional requirements. It is mainly using the UL 1598 as basis covering the different aspects of: constructional requirements, electrical and mechanical requirements, IP rating, photobiological safety and markings. Special requirements are considered for HID, FL and LED products. The UL 8800 is just a supplement to the UL 1598 which is the leading standard for such products.
Regulations	Energy Labeling	EU Regulation 2017/1369	Europe	The new EU Regulation 2017/1369 setting a framework for energy labelling entered into force as of August 1st, 2017 repealing EU Directive 2010/30. A few important changes are the rescaling of the energy efficiency label where products shall only be labeled with the energy efficiency classes A to G, an implementation of a central product database on energy efficiency and introduce a safeguard procedure to improve national market surveillance. This central product database allows customers to be more aware of the energy efficiency and energy consumption of household appliances, which will help them reduce their energy costs. Besides the information about the actual energy efficiency of the product class, the full spectrum of classes also needs to be shown on the label.
Lighting	LED	Order No. 6-E/2017	Argentina	On 1 August 2017, the Ministry of Energy and Mines published Order No. 6-E/2017 which approves the technical specification for LED lighting. This Order should be read with the Energy Efficiency Plan approved by Resolution No. 84-E/2017. The specified technical specification is mandatory. Requirements: • Luminaires shall be of adequate size to function properly with LED power and must have a nominal voltage of 220V ± 10% and a frequency of 50 Hz. • Technical information must be provided in the Spanish language. • Lighting for installations shall be suitable for columns of horizontal, vertical or suspended suspension with steel cables. • Lighting cases should be able to be placed in horizontal/vertical davit of 60 mm or 42 mm in accordance with the standard IRAM AADL J2020-4.
Lighting	Luminaires	Updates in Books	Int.	Zhaga, an industry-wide consortium has a series of books in which Book 1, Book 12 and 13 were recently updated. Book 1 contains general information relating to all the other interface specifications had got a new edition published in Jun '17. COB holders as well as COB LED arrays is included in Edition 1.1 of Book 12. Zhaga published a significantly updated version Edition 2.0 of Book 13 in Jun' 17, which aims to reduce the complexity in the market by significantly lowering form factors from 78 as in Edition 1.0 to 27 in Edition 2.0. A few more changes/adjustments are as mentioned below: • Some editorial changes and cleaning up on definition already in book 1 • Addition of MD-SIG power interface to scope and references • Functional requirements & tests are removed in Clauses 3 & 6
Lighting	LED	EN 62717:2017	Europe	CENELEC published EN 62717:2017 in June 2017 which specifies the performance requirements for LED modules. The requirements of this standard relate only to type testing and is based on the IEC 62717 + A1 with modifications to align with the EU ErP requirements for LED modules. Few modifications are listed below: • Additional definitions • Several changes of references • Additional clauses Z1 & Z2 • Replaced normative Annex A with measuring method considering EN 13032-4 and EN 61341 • New Annexes ZZA, ZZB, and ZZC to show compliance with the ErP regulation
Lighting	Fluorescent Lamps	TIS 2337-2557	Thailand	Thai Industrial Standard TIS 2337-2557 was adopted on 14 August 2016, specifying energy efficiency requirements for ballasts for tubular fluorescent lamps. This standard prescribes the energy efficiency requirements for ballasts for tubular fluorescent lamps for general lighting purposes in different shapes. It covers the following: • Minimum energy performance standard of ballasts for tubular fluorescent lamps • Ferromagnetic or electronic ballasts use with fluorescent lamps, a.c. supplies from 10 W to 70 W, voltage of 220/230 V and 240 V at frequency of 50 Hz • Ballast as a separate component or built into the lamp This standard is entered in force on 16 August 2017

A free training can be arranged for a clear understanding of the upper stated standards.
For further information on the latest upgrades and testing standards and training, please contact cps@tuv-sud.com

CIE Calls for Focused Research Efforts to Support Healthful Lighting Recommendations

Not so long ago, vision scientists thought that light detection - photoreception - was exclusively performed by rod and cone cells in the retina. Photobiologists, however, conclusively demonstrated otherwise with the identification of the intrinsically photoreceptive retinal ganglion cells (ipRGCs) [1]. Whereas rods and cones detect pattern and color, and send this information to the visual cortex, ipRGCs (of which we are learning there are several subtypes) detect irradiance, and route their information to many brain structures. The most thoroughly studied of these is the suprachiasmatic nucleus of the hypothalamus, location of the central circadian clock, where the light and dark signals trigger the offset and onset of production of the hormone melatonin. As shown in figure 1, however, ipRGCs also project to other structures, about which, as yet, we have little information.

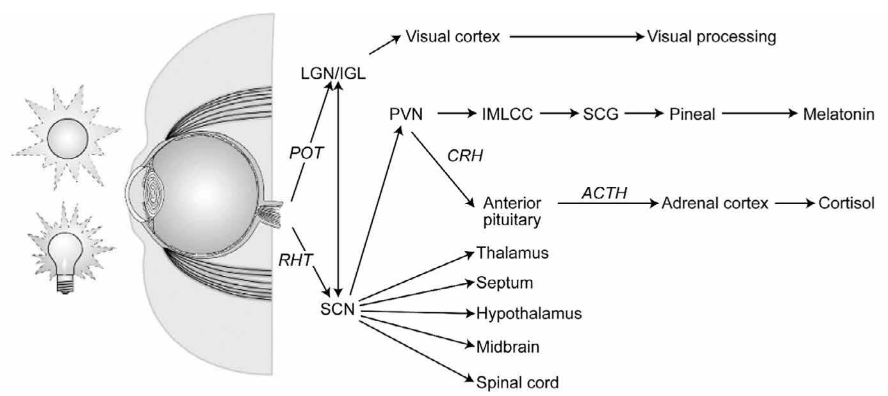


Figure 1: The Schematic diagram of eye-brain pathways (2). Light received by the eye is converted to neural signals that pass via the optic nerve to two pathways, one visual and one non-visual.
POT = Primary optic tract
RHT = Retino-hypothalamic tract
LGN/IGL = Intergeniculate leaflet of the lateral geniculate nucleus of the hypothalamus
SCN = Suprachiasmatic nucleus of the hypothalamus
PVN = Paraventricular nucleus of the hypothalamus
IMLCC = Intermediolateral cell column
SCG = Superior cervical ganglion
CRH = Corticotropic releasing hormone
ACTH = adrenocorticotropic hormone

The five principles of healthy lighting:

- The daily light dose received by people in Western (industrialized) countries might be too low
- Healthy light is inextricably linked to healthy darkness
- Light for biological action should be rich in the regions of the spectrum to which the non-visual system is most sensitive
- The important consideration in determining light dose is the light received at the eye, both directly from the light source and reflected off surrounding surfaces
- The timing of light exposure influences the effects of the dose

The CIE published the first consensus report about the physiological and behavioral effects of ocular light exposure in 2004 [2], establishing five principles (left fact box) of healthy lighting that remain valid with current knowledge.

The potential to use light to benefit well-being is huge, and excitement to do so quickly is high. However, alongside the possible benefits also come risks. Acting on imperfect knowledge, it is possible to cause unintended harm. The CIE, therefore, continues to call upon researchers to provide more and better knowledge that can serve as a strong foundation for the next generation of guidance and standards, while also providing tools and collegial opportunities to aid them in that work.

The identification of ipRGCs sparked a dramatic increase in photobiology and psychology research, especially among investigators of circadian regulation. In parallel there have been recurring calls for international bodies like the CIE to establish more detailed guidance concerning how we can use light exposure to benefit health and well-being. The CIE responded in 2004 and 2006 by holding expert symposia, and in 2007 and in 2011 convening workshops at CIE Quadrennial Sessions, to bring together the multidisciplinary communities of researchers with an aim to develop consensus.

One of the barriers to consensus has been the need for a new quantity with which to characterize this light exposure. The lumen is irradiance weighted by the visual spectral sensitivity function, V_λ. This is the wrong quantity to use for characterizing the dose received by the ipRGCs, because they respond differently than do the cones, which are the basis for photopic vision. Indeed, the demonstration that melatonin suppression followed a different spectral sensitivity than the rods or cones was part of the logic leading to the identification of the ipRGCs. When several researchers had proposed slightly differing spectral sensitivity functions for the ipRGCs, CIE supported an expert workshop, attended by the key researchers in that field, at which the group developed the first consensus-based action spectra for the five known photoreceptor types (ipRGCs, rods, and the short-, medium- and long-wavelength cones) [3, 5]. The CIE report of the workshop, which is freely available from the CIE Website, includes an Excel toolbox with which to calculate for any spectrum the light dose received by each cell type in SI units.

Why is this important? Without such a tool, it is impossible to compare research papers in terms of the dose-response relationship, especially when researchers are inconsistent about reporting the spectral power distribution of the light sources used in their studies (indeed, sometimes inconsistent in reporting any details at all about the light source). If we do not know what light exposure or total dose was received, we cannot judge whether two papers are consistent or not in finding the same effects. In order to further advance the effort to improve communication about these effects, as well as to provide a foundation for future guidance and application standards, CIE JTC 9 is currently engaged in the development of a standard for the action spectrum for this new quantity.

The toolbox, together with the standardization of the action spectrum, will be the departure point for a new research era in the field of healthful lighting, one in which it is possible to build a clear understanding of the answers to questions (right fact box).

These are a small selection of the full research agenda that the CIE has placed as an inspiration and a challenge to the research community [4]. The answers are urgently needed, not only to address the hunger for integrative lighting solutions and methods to deliver what some have called "human-centric lighting", but also to resolve the inherent tension between those who seek to deliver a higher daily light dose for well-being, and those who seek to use less energy for electric lighting. By highlighting this field, in its 2016 Research Strategy, the CIE seeks to focus attention on developing the information the world awaits, so that everyone can enjoy the proper light at the proper time. ■

Some questions being answered:

- What pattern of daily light and dark exposure (intensity, spectrum, timing, duration) best supports well-being, both for circadian regulation and acute effects during waking hours (e.g. alertness, emotion, social behavior)? How does this vary throughout life, from infancy to old age?
- In addition to circadian regulation, what physiological and psychological processes are influenced by ocular light detection?
- There are known medical uses of light to treat certain skin disorders and hyperbilirubinemia. There is speculation that inadequate light exposure during childhood contributes to the development of myopia. These ideas lead to the general question: Are there behavioral or physiological effects of extra-ocular absorption of optical radiation that should influence lighting recommendations?

References:

[1] D.M. Berson, F.A. Dunn and M. Takao, 2002. Phototransduction by retinal ganglion cells that set the circadian clock. Science, 295(5557), 1070-1073.
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Tech-Talks BREGENZ - Dr. Wilfried Pohl, Research Director, Bartenbach GmbH

Wilfried Pohl

Dr. Wilfried Pohl studied mathematics and physics. He has been a member of the Managing Board and the Director of Research at Bartenbach since 1998. He deals with daylighting and artificial lighting, the development of (artificial and day) lighting devices, optical design, photometrical and thermal measurements, calculation and simulation tools, lighting fundamentals, building physics (in connection with day lighting, sun protection, cooling and heating), visual perception and light and health. He was the leader of diverse international planning and R&D projects in these fields. He has published numerous scientific publications and is a lecturer at various universities.

Bartenbach is one of the pioneers in light planning and lighting research. Since Christian Bartenbach Senior founded the engineering office in 1976, the company has been dedicated to light and visual perception. Several lighting inventions made over the years, can be attributed to Bartenbach. Dr. Wilfried Pohl, as a member of the Managing Board and Director of Research at Bartenbach GmbH, has played a substantial role in many developments. LED professional talked with him about Bartenbach's history, education in the lighting business, the lighting parameters he deems very important, the quality of light, "Human Centric Lighting" and "Biodynamic Lighting", and how LEDs have changed the light planning and lighting research company, in general.

LED professional: First of all, we'd like to express our appreciation for taking the time to come to Bregenz for this interview.

Wilfried Pohl: Glad to be here.

LED professional: To start, could you tell us a little about Bartenbach? How did it come to be? How has it developed? What is Bartenbach's current position?

Wilfried Pohl: Bartenbach is an engineering office, founded by Christian Bartenbach. Our founder, who is now 87 years old, turned over the business administration to his son, Christian Bartenbach Jr. in the year 2007.

Light interested Christian Bartenbach Senior from an early age and as a young man he made contact with a group of psychologists that were interested in light and visual perception. It fascinated him to such a degree that he decided to open a light planning office. That was in the year 1976, when light planning offices were few and far between and light planning was considered exotic.

A mirror louvre luminaire for FK lamps. This technology was invented by Christian Bartenbach Sr., but never patented by Bartenbach

LED professional: How was he able to finance the company?

Wilfried Pohl: From the beginning, Christian Bartenbach's goal was to find architects and building contractors that were agreeable to the concept that good light planning was a necessity. Architects were especially open to this idea because they saw light planning as a defining characteristic that they could use. Everything was financed through the light planning contracts. Through the planning orders it was possible to constantly develop new luminaires that were designed to accommodate the special performance requirements of the projects.

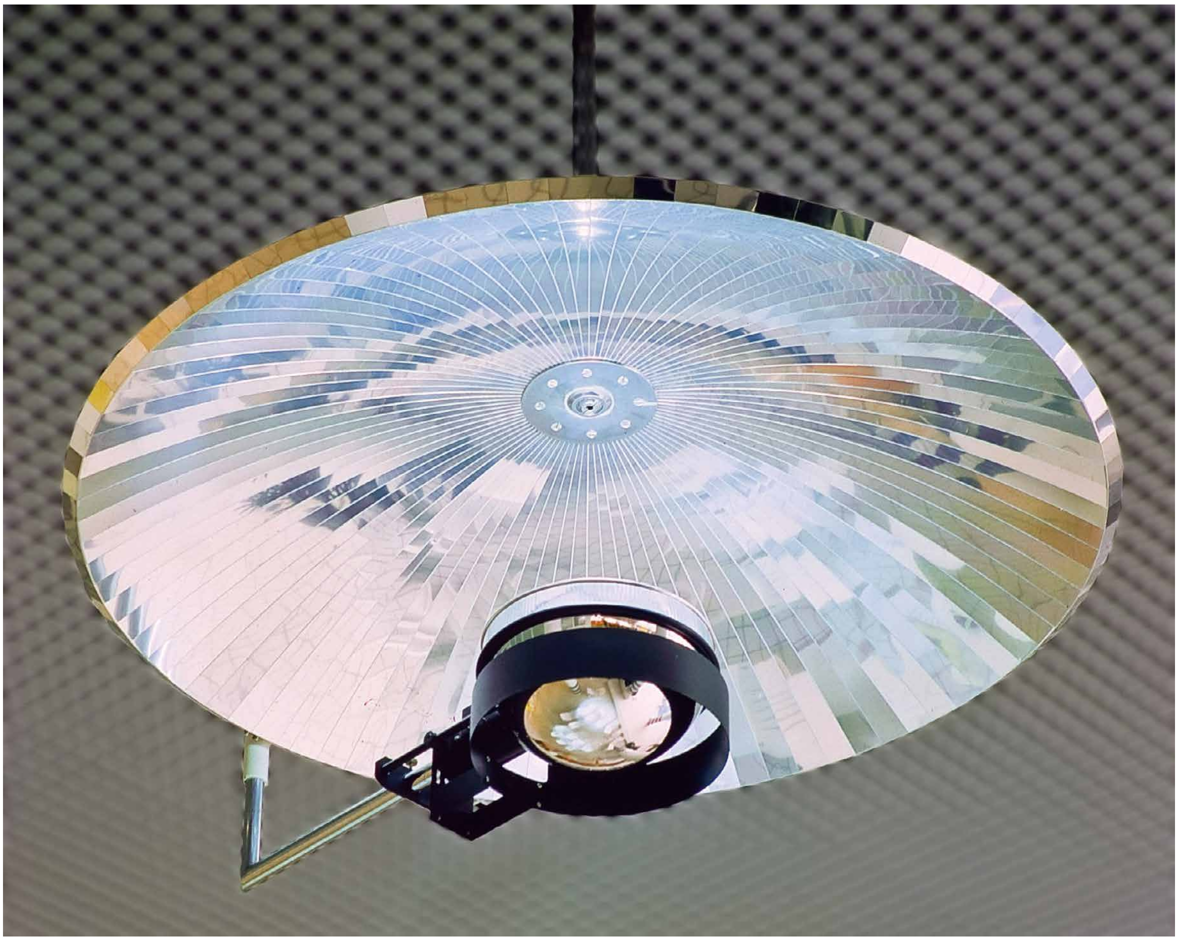
LED professional: Could you give us a couple of examples of the special luminaires?

Wilfried Pohl: Bartenbach Senior was, for example, the inventor of the mirror louvre luminaire. Even though the fluorescent lamps in those days (I'm referring to the old T12 lamps), had moderate luminance, he decided to shield the lamps in order to avoid psychological glaring. The mirror louvre luminaires were never patented by Bartenbach, which meant that he missed the chance for licensing them and earning a lot of money. Within a very short period of time every luminaire manufacturer started producing them. And that's how that technology became the conventional office solution.

LED professional: Were these luminaires produced by Bartenbach?

Wilfried Pohl: No, the luminaires developed by Bartenbach were always included in the tender and manufactured by the supplier. Of course this caught the attention of the luminaire manufacturers because they were always looking for innovations, and very often they included them in their catalogues as a serial product. Another development was the secondary reflector technique, where the lamp couldn't be looked at directly from any angle.

Bartenbach was one of the first to design secondary luminaire systems to prevent a direct view of the lamp and reduce glare



LED professional: And Bartenbach was able to finance the development of all these new systems?

Wilfried Pohl: Yes, it was all financed through the planning. In those days, building contractors were willing to pay for the analyses of the benefits of a new solution as well. We received additional contracts for luminaire developments and, of course, for our analyses in the context. Later on, that stopped. The market changed and around 1995 research couldn't be financed like that anymore. Building contractors were less and less apt to take part in that type of adventure in the course of a building project - and research and development as part of a construction project is always an adventure. You are always encountering unexpected problems that have to be solved.

LED professional: What were Bartenbach's key arguments that would convince the client to hire you?

Wilfried Pohl: One key argument was the quality of lighting. Those were the days of the first screens. Bartenbach carried out intensive studies, where computer screen work stations had been set up, the surrounding brightness was varied, and the screen luminance were adjusted. With the results you could plan lighting systems that could increase the visual performance significantly, e.g. reduce the frequency of mistakes made and decrease mental strain, etc. But to get back to the story, from 1995 on, the R&D department became its own profit center and has had to support itself. We develop, for example, optical components that are sold independently of our planning projects. In the meantime we have about 10 employees that work solely on optical design. The optical designs are developed and then licensed. Today a lot of companies manufacture products that were developed by Bartenbach, mainly in Europe, but also in India, America, to name a few.

LED professional: Could you tell us a little about the Lighting Academy?

Wilfried Pohl: The Academy was started in 2003. An academically recognized, 2-year master course was established. Through the training course, Bartenbach was able to acquire a lot of good people, but especially important was the fact that we were able to anchor light consciousness in the mindset of society and of many international companies through the graduates that work all over the world. The course used an enormous amount of resources at Bartenbach and even though there was a significant tuition, it wasn't self-financing. Because of that, new management thought it best to discontinue the master course in 2015.

LED professional: I'd like to talk about the subject of research. You started out with conventional light sources and did research in this area. About 15 years ago, the gradual change over to

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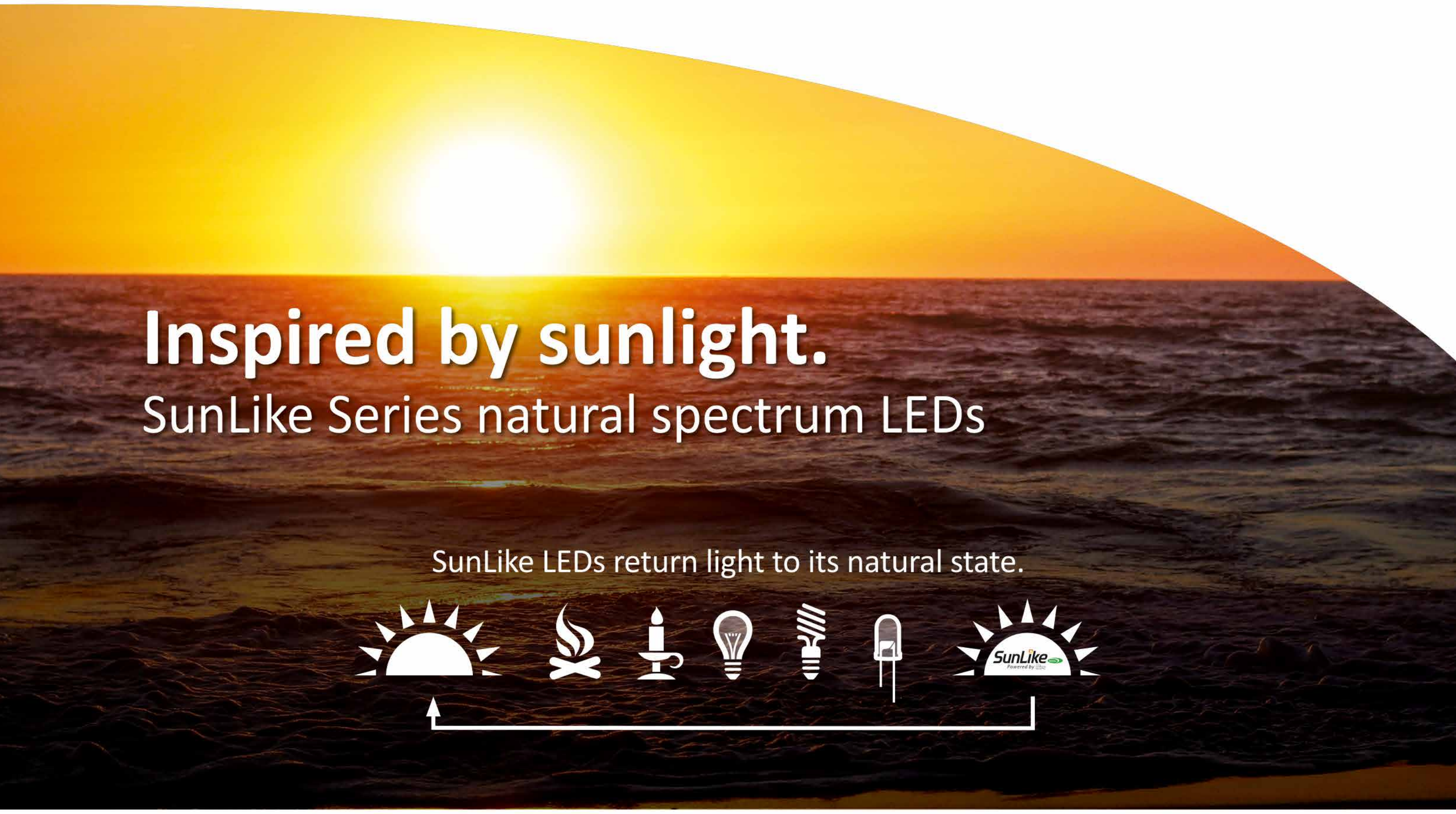

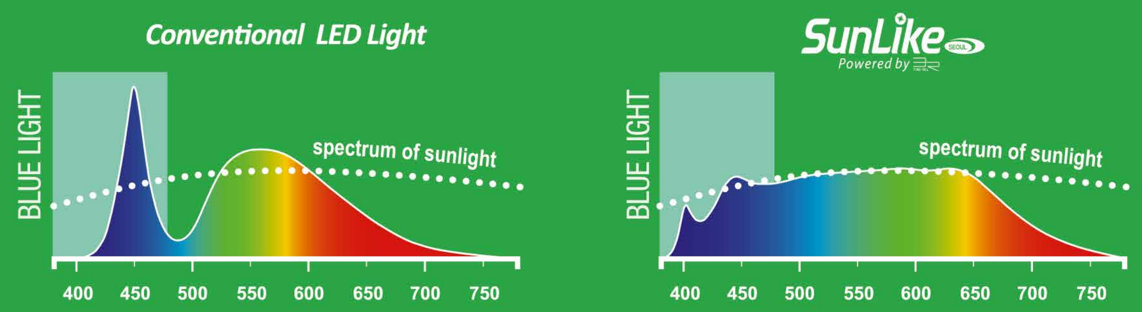

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LED began. How did this new technology influence the focus of your research?

Wilfried Pohl: Our research has two focal points. On the one hand, the area of perception and light impacts, and on the other hand, we do research in the area of technology. This includes calculation and simulation programs, new materials, energy efficient buildings and daylight. But the LED completely shifted the focus of our research in the area of artificial light. Bartenbach Senior again proved his farsightedness by equipping a meeting room with LEDs in the year 2000. At that time the LEDs had a power of 0.1 Watts and a light flux of 1 lumen. In hindsight, I have to say that it was the right decision. At that time, even though the LED was being intensively publicized, not many building contractors were working with it, and for those that did, the cost of learning was high. The quality of the lighting wasn't right, energy savings were minimal and the LED's including the drivers very often broke down after a couple of years. But because of our early start we were able to acquire a proportionate lead.

LED professional: And are there light effect research subjects that have evolved through the LED that didn't play an important role before?

Wilfried Pohl: I would say that the subjects have come up again. Many of the problems that early illuminants had have surfaced again with the LED. I can remember that the subjects of high luminance, photobiological safety, glare and UV were being discussed intensely in the year 1985 in regards to the upcoming metal halide lamp. And those are the topics that are being discussed again in regards to the LED because the LED has already surpassed the metal halide lamp in relation to luminance. Photobiological safety must also be taken seriously. During the last few years it hasn't been relevant for research but in the meantime it has gained a significant amount of importance.

LED professional: Isn't blue light hazard a subject in regards to LED? Have you examined it? It keeps coming up as a topic for discussion but no one really knows how to classify it.

Wilfried Pohl: Yes, it is indeed a topic. Although I have to say that the blue light of an LED is no bluer than earlier illuminants. But our studies are mostly on glare, which is the more harmless topic area, but the threshold is much lower here. If you avoid glare, there's no danger for the eyes. Generally, I have to install the illuminant so that the radiation is never in the viewing direction.

LED professional: How important is the subject of energy efficiency for Bartenbach?

Wilfried Pohl: Although lighting quality rather than energy was the focus in the past that has changed over the last few years. Today we can also argue that you can save energy through a combination of daylight and artificial light. But the deciding point is still the quality of light. For example, one of the main things that needs to be done when you are using daylight in the building is to avoid glare. As an example, in this room we're in I would guess that we have a sky luminance of a few thousand cd/m² at the window and here at the table about 80 or 100 cd/m². That is a ratio of about 1:50 and it's not that easy to cope with if visual performance is necessary. But light also has an emotional quality and that's why a view through the window is important. So it has to be decided whether I want to look out the window and enjoy the view or if I have to work on a computer screen.

LED professional: Theoretically speaking, can you underpin something like that?

Wilfried Pohl: Yes. On that score we have developed a visual perception concept. We based it on a PhD study from Schumacher, who measured contrast sensitivity with various background brightness. The question is, how much of a contrast does there have to be, for example, between a letter and the paper in order for it to be seen. The threshold of visibility depends on the surrounding brightness. If it is too bright, the contrast sensitivity decreases dramatically, which means that it becomes more difficult to see and read the letters.

LED professional: But how do you find common ground between these quality requirements? On the one hand, I have to reduce the light intensity from the window, dim it, in order to avoid glare and to fulfill the visual task. On the other hand, I have lost my view of the outside and this demotivates me because I feel like I'm locked in.

Wilfried Pohl: That is the real challenge - to be able to deal with these contradictions. There is not one single solution that is right for every case. If you are very concentrated on your work, the surroundings don't play a role, but in phases when you are less concentrated, the view is more important. You could use a controllable system where the user can decide but the user can't decide everything, he also needs the support of the controls.

LED professional: After so much research, are there hard facts available today? Do we know what the effects of a flawed light situation is in comparison to an optimized light situation? Are the figures available that confirm the reduction of sick days or higher efficiency?

Wilfried Pohl: There are a large number of studies but the results are mostly vague. And they'll always be weak. People's health is dependent on so many things that it just isn't possible to determine an unambiguous cause-and-effect relation. It's more a question of proving the evidence. Bartenbach also had the idea of measuring physiological data. Earlier, all the studies were made with questionnaires, and you don't get hard facts from questionnaires, .

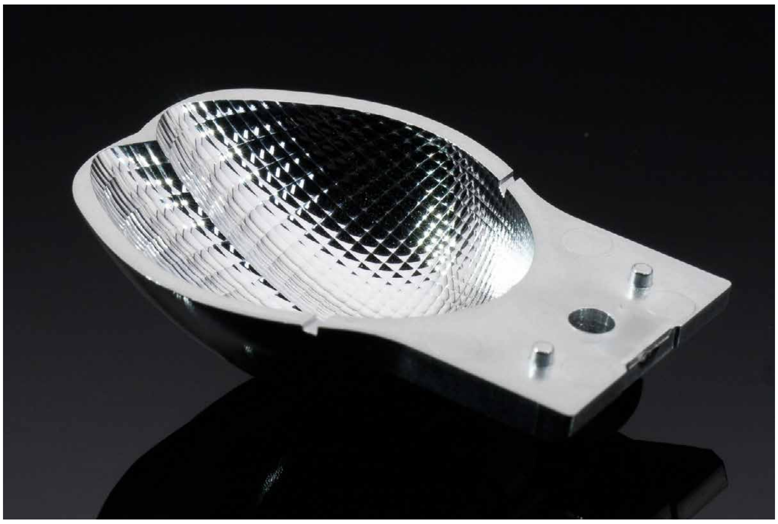
LED professional: What physiological data can be compiled in order to receive objective statements?

Wilfried Pohl: For example, the conductivity of the skin, which is a stress indicator, was measured. If you are under stress, you begin to sweat, the skin becomes damp and conductivity increases. Later we measured heart rate variability, but interpreting that data is difficult. A small amount of variability means that you are tense and a larger amount of variability means you feel more comfortable. But a detailed interpretation of the data isn't as unambiguous.

LED professional: Research is very expensive. How does Bartenbach finance things like perception studies?

Wilfried Pohl: We submitted our first EU funded project proposal in 1997. Besides the EU, the Republic of Austria was also a strong supporter of our research. We usually have 20 to 30 research projects running at one time and many of them are

Dr. Pohl talked about the combined use of daylight and artificial light in buildings with Siegfried Luger and Dr. Sejkora in a typical meeting room with an estimated luminace of 80-100 cd/m² at the table and a sky luminance of a few thousand cd/m² at the window



The development of optics for LED luminaires - like this tiny IP protected free-form optics - is one of the company's main business branches

funded. On the other side, we sell many of our perception studies and finance ourselves with that money. Amongst others, our clients are large corporations who need some basics in these fields.

LED professional: We were talking earlier about glare. It has always been Bartenbach's opinion that artificial light should narrow beam with sharp cut-off in order to avoid glare. Is that a guiding principle for planning in every respect?

Wilfried Pohl: I think that with certain applications you have to change your way of thinking. Systems with a sharp cut-off can cause "light pressure" and the necessary vertical illumination has to be created in a different manner by using the surfaces in the room. The walls have to be targeted with wall washers. At the end, every point of the room needs, what I call, a balanced radiation field.

LED professional: That sounds like a very complicated solution. What alternatives are available?

Wilfried Pohl: Yes, these lighting solutions have to be planned very carefully. You can also make the luminaire with a larger and diffuse light outlet area and get away from the point light source. Due to the resulting glare and uncontrolled light distribution that used to be taboo for us. Indirect lighting was developed 30 years ago, and later came mellow light. It's clear that a luminaire that emits diffuse light will create glare, but you have to ask yourself how big the disturbing effects will be. Even a narrow beam downlight without any glare in the viewing directions has its disadvantages. We, at Bartenbach are in the process of discussing this and changing our way of thinking.

LED professional: So you're talking about a solution with shielded direct light and diffuse share?

Wilfried Pohl: Yes, but you have to keep the high luminance of the LED in mind. Especially the future technological development with semiconductor lasers - if you look at the beam, you'll be blinded. Here you will have to think carefully about how to use the laser light sources. The question is whether or not we can implement it into general lighting.

LED professional: At first everyone appreciated the LED because we finally had a point light source available. Now, the trend seems to be that we're moving towards mid power LEDs and we're trying to make surface light out of the numerous small point light sources. Is that a sensible use of LEDs?

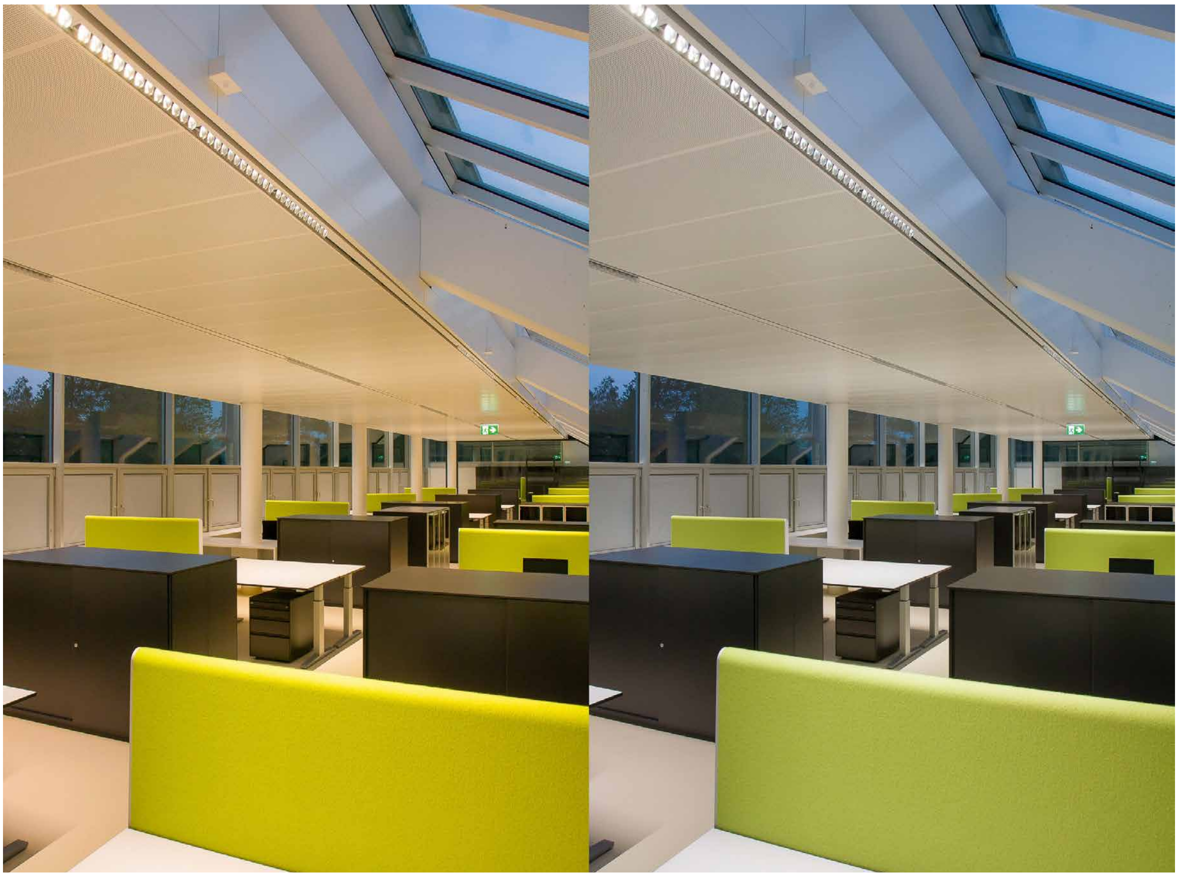
Wilfried Pohl: Actually, it has always been my opinion that that is absurd. We now have a point light source with high brilliance. Perhaps just a word about brilliance. If I look at a surface, it always has a certain amount of gloss and a structure. It makes a very big difference if I shine a point light source or a diffuse light on it. The surface has a completely different look and feel. Depending on the use, I need a mixture of brilliant light and diffuse light. The LED is a wonderful substitute for the light bulb because it also creates brilliant light. And we need that. But we also need diffused light. You can make it with indirect lighting - and that's how we do it. But it is certainly also ok to line up a lot of low power LEDs behind a diffuser. In any case, I shouldn't use a high power LED for it.

LED professional: Do you have, for example, OLEDs in mind? Would that be a suitable source for the diffused part?

Wilfried Pohl: It seems to me that things have quieted down quite a bit lately when it comes to the OLED. At the beginning we worked on research projects but in the last while, there isn't much going on. Evidently the OLED failed because of technological problems, especially when it came to mass production. Actually, the OLED would complement the LED perfectly. That way we could combine a high quality surface light source with a brilliant point light source. Unfortunately the OLED has technological problems and the consequence is that it is much too expensive.

LED professional: How much is known about biological light effects today and how is it taking into account during the planning stage?

Wilfried Pohl: The future of light depends on quality. And biological quality is a part of that. We have the technology to do whatever we want with the LED with a high degree of energy efficiency. But there aren't metrics for the concepts I talked about earlier, not only for biological qualities, but even for visual qualities, e.g. like brilliance or radiation field. I can't measure brilliance and there aren't any quality criteria for it. Another example are the risks of LED lighting.



Human Centric Lighting is one of the trends in the lighting industry. Biodynamic lighting would probably be the more accurate way to describe scenarios like this one: Part of Bartenbach's office in the late afternoon illuminated with 2700 K (left) and 4000 K (right). The effect on people is one question Bartenbach strives to answer with their perception studies

E.g. how we deal with photobiological safety is inadequate and must be regulated. The norm EN62471 leaves a lot of things open, contradicts itself in some parts and has technological mistakes. Many metrics are missing for visual evaluation or they are outdated. In regards to spectral quality, many steps need to be taken and a lot has to be updated. We need to make lighting quality measurable.

When we talk about biological effects, we find that there are no rules. Today, if we want to achieve biological effects, we start from vertical illuminance at the eye. But if we think it through, we arrive at completely different requirements from those we used to have. We always planned for horizontal illuminances and now we find ourselves with an evaluation that is oriented on humans and requires vertical illuminance. How can I generate biologically effective light at a desk? How can I generate 1,000 lux near the eye without creating glare? Physically, it's just not possible. And this dilemma is just going to get worse in the future because we'll need even higher illuminances near the eye.

LED professional: That means that what we have made up until now has been wrong and what we're doing is contradictory. Isn't that a big problem?

Wilfried Pohl: You can see it as a problem or as a chance. We are working on completely new concepts to find solutions. We have to find a way for the luminaire to blend into the surrounding luminance and then it can't cause glare. At the same time we have to achieve high illuminance near the eye, and I can only achieve that through the surface areas of the room. That means that it will become increasingly important for the room to be used as a reflector and to include the surfaces in the room in the planning stage. Otherwise there is no chance to achieve a biologically effective amount of light at the eye. We call it the "integrated concept" and it gives us the chance to push lighting design, which is our service, to the forefront. In addition, it is also the chance to develop new concepts and new luminaires.

LED professional: What would these types of light solutions look like?

Wilfried Pohl: There are a few different approaches. Bartenbach, for example, would propose a solution that integrates the entire room. Of course, that would be complicated, but from our point of view, it would be the best way to achieve all the requirements. Another might just put a floor lamp in the room and claim that the biological effect has been achieved. And another person would use a desk lamp. And if they claim that they are making Human Centric Lighting (HCL), I don't think it would be very plausible. But nevertheless we think that the future lies in "biodynamic light". That's light with corresponding controls and intelligence that is tunable regarding color temperature, intensity and distribution.

LED professional: How much is Bartenbach affected by the subject of Smart Lighting?

Wilfried Pohl: There is a point of contact there. Of course we are keeping our eye on what is happening on the market and we know the state of the art. But if we want to make biodynamic light, we are aware of the fact that the different proprietary systems are unable to cope. There are enormous implementation problems; certain control and regulation requirements that aren't supported by the systems.

LED professional: You mentioned biodynamic light and variable light color. Generally, we only think about the color temperature. How important is the actual spectral distribution?

Wilfried Pohl: I believe that for spectral quality the actual power distribution is also important. Of course we are now at a high level, but in regards to color rendering, there is still room for improvement. But the metrics will have to be adjusted so that a proportionate improvement potential can be described. LEDs, especially, have certain differences that cannot be quantified with current metrics. Researchers agree that there is also room for improvement when it comes to the "whiteness" of light. It is also possible to achieve some improvements in regards to the biological effects by optimizing the spectral distribution at the same color temperature. Summarizing, the spectral quality must be describable with additional coefficients and not through color temperature and color rendering alone.

LED professional: In connection to HCL we hear a lot about the biological effect of light. What do we know about that, exactly?

Wilfried Pohl: The hardest facts that we know today describe the nightly suppression of melatonin. Melatonin dumping was measured from the pineal gland. In the dark, at night, it has a constant, high value. If the test person is subjected to light, the release of melatonin sinks to almost zero within minutes. The effectiveness is proven for nighttime but there aren't any hard facts for the daytime.

LED professional: Does that mean that if I work at night, or drive a car, I need to be proportionately lit up in order to suppress the release of melatonin and not get tired?

Wilfried Pohl: For a long time, that's what we thought. Today, the opinion is rather that we have to be careful with melatonin suppression. Medical practitioners are of the opinion that the nightly suppression of melatonin can promote cancer. In the US, they have even gone so far as to warn people about the use of LEDs. And chronobiologists agree that we should disturb the biological clock as little as possible with light. So the common approach now is that we should use light at night in a way that avoids melatonin suppression as much as possible. We have carried out studies in which we proved that the use of light with a lower color temperature (we went down to 1700 K in our study), doesn't block melatonin. Today we go up to 2200 K - that's enough and it is a lot more comfortable. Our study also showed that despite the absence of melatonin, concentration was not reduced.

LED professional: Bartenbach will be running a workshop on the subject of "Visual Perception" at the TiL 2017 in Bregenz. What can you tell us about this workshop?

Wilfried Pohl: It is a great chance to display and demonstrate some of our insights. We are hoping to inspire people with a few suggestions for completely new lighting concepts. We want to sensitize people to the subject and start discussions. In contrast to what we did a few years ago at the LpS, we not only want to talk about visual effects but we are also going to focus on biological effects and Human Centric Lighting.

LED professional: Thank you again for making the time to come to Bregenz and for this interesting interview. We appreciate it.

Wilfried Pohl: My pleasure. ■

Measurement of Angular and Spatial Resolved Spectral Rayfiles

The enhanced complexity of modern lighting systems has increased the importance of realistic light source models during the optical design process of LED-based luminaires. I. Rotscholl, Research Associate, K. Trampert, C. Neumann, I. Leopoldo Sayanca from the Karlsruhe Institute of Technology, U. Krüger and F. Schmidt from the TechnoTeam Bildverarbeitung GmbH, propose a method to enhance the often used LED light source model "rayfile" towards a "spectral rayfile". A spectral rayfile would be a model that associates each ray with its own spectrum and therefore describes varying spectra as a function of angular direction and spatial starting position. The PMBS (physical motivated basis spectra) method is based on the assumption that each LED spectrum consists of a weighted sum of individual basis spectra, for instance those of individual semiconductors and phosphors. There is no need for any special measurement equipment but a classic nearfield goniophotometer and some off-the-shelf optical filters. This method requires at least one spectral measurement and just a minimum of goniophotometric measurements with different optical filters. Finally, the authors demonstrate the potential of this method by applying the concept on a typical LED and compare the results to the often used Blue/Yellow approach in terms of accuracy and applicability.

Due to the evolution of the new light source technologies LED and OLED, lighting technology has become more than the efficient creation of light. The new light source technologies are more efficient than the conventional sources and they also offer the possibility to tune colors and spectra. Therefore light colors and spectra and their physiological as well as psychological effects on humans in daily situations, for instance their influence on the learning process of school children [1], are currently an important aspect of interdisciplinary research called human centric lighting. However, there are problems if those actinic spectra are not only generated but shall be generated efficiently in complex optical systems.

Optical system design bases mainly on reflection, refraction and scattering and sometimes diffraction. However, all effects are not only functions of angles of incidence but also include wavelength dependencies. This may lead to color fringes or other undesired spectral artefacts. Unexpected artefacts may also occur if there are spectral variations of the light source, as for instance, phosphor based white LEDs, whose spectra often change strongly as a function of emission angle due to different phosphor conversion lengths. There may also be spectral variations as a function of spatial dimension, which might result from different LED positions or different environmental conditions such as the temperature distribution on the board. Therefore an efficient detection and prevention of spectral artefacts during the optical design process in modern ray tracing software is only possible if accurate spectral, angular and spatial resolved information is available within the light source model.

In this article, we will focus on the direct measurement of spectral light source models of LEDs. After a brief summary of current methods, we will introduce a fast and accurate measurement method to create such models and test the method with one example.

▶▶ p 53

LPS 2017 PROGRAM | SEPT 26TH

TiL TRENDS IN LIGHTING

Time	Technologies Seestudio	Markets Saal Bodensee	Lighting Propter Homines	Forum Seefoyer
08.00	**WORKSHOP** **OLEDs - Bring Your Design to Light** *by OLEDWorks*	**WORKSHOP** **Visual Perception - Theory, Practical Demonstrations, Limitations** *by Bartenbach*	**WORKSHOP** **Challenges and Opportunities of LiFi** *by Photonics Austria & Fraunhofer*	**WORKSHOP** **Bluetooth Mesh and IoT/Smart Control Panel Discussion** *by Silvair & Bluetooth SIG*
08.30				
09.00				
09.30	COFFEE & LpS EXPO / TiL SHOW			
10.00	**Challenges and Future of LEDs** *Ki-bum Nam* *Seoul Semicondutor, CTO*	**Lighting Delivering Increased Value to Society - A Strategy for Growth** *Ourania Georgoutsakou* *Lighting Europe, Secretary General*	**Theory of Light - Reloaded** *Dr. Stefan Kreidler* *onlog, Network & Innovation Manager*	**Exhibiting with LED Lighting - Museo dell'Opera del Duomo in Firenze** Massimo Iarussi Studio Massimo Iarussi, Founder & Lighting Designer
10.30	**Spectrally Narrow Red Quantum Dots in White LEDs for General Illumination** *Dr. Ken Shimizu* *Lumileds, Technical Director*	**2017 LED Industry Update: Highlights and Future Trends** *Pars Mukish* *Yole Développement, SSL & Display BU Manager*	**Lighting Quality for the Next Decade - Visions and Mission for the Lighting Industry** *Horst Rudoph, ITZ/Trilux, Director Research and Lighting Technology*	**Light Management Meets IT Technology** Sven Müller ITZ/Trilux, Director Lighting Systems
11.00	**Laser Lighting: Opportunities and Criticalities** *Dr. Nicola Trivellin* *LightCube, CEO*	**LEDification: A Work Still in Progress** *Dr. Norman Bardsley* *Bardsley Consulting, CEO*	**Good Light Above the Clouds** *Prof. Volker von Kardorff* *Kardorff Engineers, CEO*	**How Lighting will Become a Secondary Function of the Luminary** Bastiaan de Groot Feilo Sylvania, Global Director Strategy & BD
11.30	**Lighting Industry Quo Vadis** *Klaus Vamberszky* *Zumtobel Group, EVP Technology*	**The Fairhair Alliance Facilitating the Internet of Things for Commercial Buildings** *Teresa Zotti* *Philips Lighting Research, Scientist for IoT Systems*	**Melanopic Photometry vs. Melanopic Lux - The WELL Standard as a Case Study** *Dr. Octavio L. Pérez* *Mount Sinai Hospital & Lledó Lighting, Researcher*	**Is Smart Lighting Smart in the Eyes of the Customer?** Dr. Thomas Knoop Zumtobel Group Services, EVP
12.00	LUNCH & LpS EXPO / TiL SHOW			
13.00	**Colorimetry and Variability of LEDs** *Dr. Thomas Merelle* *Pi Lighting, Senior Consultant*	**Interoperation of Street Lighting CMS within IoT Urban Ecosystems** *Arturo Rubio-Dobón* *ELT, Business Development Manager*	**SCHEER Report - LED Potential Risks to Human Health** *Axel Baschnagel* *LightingEurope, Communication Consultant*	**Artificial Sky - The Evolution of the Sun Indoor and the Moon between Poetry and Science** Prof. Paolo Di Trapani CeoLux, President
13.30	**Chip Scale Package LED Lighting Modules: Opportunities and Challenges** *Pierrick Boulay* *Yole Développement, Market and Technology Analyst*	**The Architecture of IP Connected Lights can be the Blueprint for Connected Buildings** *Thomas Moder* *Tridonic, Segment Manager Controls & Connectivity*	**Impact of Artificial Illumination on Alertness and Cognition - A Psychophysical Evaluation** *Dr. Vineetha Kalavally* *Monash University, Senior Lecturer*	**EINSTONE Smart Retail - Sales Increase for Retailers** Dr. Christoph Peitz OSRAM, Director EINSTONE Business
14.00	**Design, Substrates and Processes for the Production of High Performance LED Flip Chip Modules** *Dr. Franz Schrank* *Tridonic, Head of Research & Technology*	**IoT Standardization Needs and Multiple Connectivity for Lighting Controls** *Dr. Walter Werner* *Werner Mgt., CEO*		**Bluetooth Mesh Networking Paves the Way for Smart Lighting as a Service** Martin Woolley Bluetooth SIG, Technical Program Manager
14.30	COFFEE & LpS EXPO / TiL SHOW			**IoT and Lighting: Affordable and Fast Time-to-Market Sensors Solutions** Kevin Jensen ams, Senior Marketing Manager
15.00				
15.30	Keynotes Grosser Saal		**Lighting Visions, Trends & Projects in Modern Architecture** *Helmut Kinzler* *Zaha Hadid Architects, Senior Associate*	
16.00			**Strategic Roadmap of the Global Lighting Industry** *Jan W. Denneman* *Philips Lighting, President Global Lighting Association & VP Philips Lighting & VP LightingEurope*	
16.30			**Digitization of Buildings** *Akshay Thakur* *CISCO, Business Development Manager*	
17.00			**Transition of Illumination - Light Centric Humans** *Fred Maxik* *Lighting Science Group, Founder & CTO*	
17.30				
18.00 - 19.00	Expo Reception Werkstattbühne		**Networking, Informal Drinks Reception in the Expo/Show Area**	

LPS 2017 PROGRAM | SEPT 27TH

TRENDS IN LIGHTING

Time	Light Sources Seestudio	Connected Lighting Saal Bodensee	Design & Engineering Propter Homines	Forum Seefoyer
08.00	**Monocrystalline Luminophores for High Power Illumination (Laser)** *Tomas Fidler* *Crytur, Research Engineer*	**Case Study: Integrating Bluetooth + Mesh Into LED Drivers and Light Fixtures** *Laurent Jenck* *ERP Power, VP Business Development*	**Latest Trends and Technologies for High-End Retail Lighting** *Sebastian Hülck* *EBV, Director Segment Lighting*	
08.30	**Communicate with Graphics from IES TM-30-15** *Markus Reisinger* *Lighting Research Studio, CEO*	**LED Drivers Overview Considering State-of-the-Art, Differentiation and Regulations** *Iván Cid Jiménez* *ELT, R&D Manager*	**Novel Encapsulation and Siloxane Materials for CSP Packaged LEDs** *Dr. Juha Rantala* *Inkron, CEO*	**Universal Use - Solar Lighting is the Topic of Today** Reinhard J. Weiss LEDON Lamp, CEO
09.00	**Understanding and Applying the Latest Eye Safety Standards to LEDs, Modules and Luminaires** *Alexander Wilm, OSRAM Opto Semiconductors, Senior Key Expert Illumination*	**Closed-Loop Sensing: Human-Responsive Lighting Delivers ROI** *Tom Griffiths* *ams, Sr. Marketing Manager*	**Thermal Management for Chip-Scale Packaged Lighting Modules** *Dr. Giles Humpston* *Cambridge Nanotherm, Applications Manager*	**Building Processes Revolutionized by a Multifunctioning Home Automation – Get Your IoT Building with Aladin** Hubert Rhomberg Rhomberg Group, Managing Director
09.30	**Opportunities in Spectral Tuning from High Color Rendition to Horticulture Applications** *Ingolf Sischka* *Lumileds, Technical Solution Manager*	**Zhaga Interface Specifications for Connected Lighting and a Circular Economy** *Dr. Dee Denteneer The Zhaga Consortium, Secretary General*	**Light Guides and Asymmetric Optics** *Dr. Marc C. Hübner* *auer Lighting, Director Optical Technologies*	**Light is Freedom of Design** Aninda DasGupta OSRAM, Head Global Marketing Digital Systems
10.00	COFFEE & LpS EXPO / TiL SHOW			**Light, Creativity & Tech** Stefan Yazzie Herbert The Paranormal Unicorn, CEO
10.30				
11.00	**Laser Light Sources for Specialty Illumination Applications** *Dr. Paul Rudy* *SoraaLaser, Co-Founder & SVP BD*	**Converging Power Supplies for LEDs, IT & Consumer Electronics with Integrated Magnetics** *Dr. Fred C. Lee* *Virginia Tech, Professor*	**Equivalently Equal Electrical, Optical and Thermal Parameters Open New Design Possibilities of LED Devices** *Olga Morozova* *Rusalox, VP Overseas Operations*	**Clever Innovation that Solves Real Problems and Reduces Costs for LED Emergency** Russ Sharer Fulham, VP Global Marketing & BD
11.30	**Hybrid Quantum Dot - Light-Emitting Electrochemical Cells** *Dr. Ekaterina Nannen* *Nano Energie Technik Zentrum, BD*	**Implementing Smart Lighting Using Bluetooth Mesh Networks: Specification Walk-Through for Lighting Professionals** *Szymon Slupik, Silvair, CTO & Chair of the Mesh Working Group at Bluetooth SIG*	**High-End Plastics for Prospective Optical Applications** *Alexander Woerle* *kdg opticomp, Head of Technology & Innovation*	**Advanced Lighting Control and Smart City Trends in the United States, Latin America and EMEA** Ian Aaron UBICQUIA, CEO
12.00	**How the Latest High-Power Silicon-Based LED Technology is Transforming Form, Function and Performance** *Giuliano Cassataro, Plessey, Sales Director*	**BLE and Cloud Based Smart Lighting Solution** *Timo Pakkala* *Casambi, CEO*	**An Optimized Gas Filling for Gas Cooled LED Bulbs** *Dr. Calogero Sciascia* *SAES, Head of Laboratory*	**DALI Version 2: Lighting Systems and Interoperability Benefit from New Standards and Mandatory Certification** Dr. Scott Wade, DALI/DiiA, Technical Manager
12.30	**Smart RGB LED Concept for Automotive Lighting Applications** *Markus Römer* *Inova Semiconductors, Manager Application & Systems Engineering*	**Smart and Secure IOT LED Streetlight with Digital Driver Technology** *Ulrich vom Bauer* *Infineon, Senior Segment Manager*	**Accelerated Development with Virtual Prototyping for Lighting Industry** *Kamill Przygoda* *Optis World, R&D Engineer*	**Are You IoT-Ready™?** Evan D. Petridis Enlighted, Chief System Architect
13.00	LUNCH & LpS EXPO / TiL SHOW			
14.00	**Future Performances in CRI for Indoor and CCT for Outdoor Lighting** *Xavier Denis* *Nichia, Application Engineering Mgr.*	**IoT System Architectures of BMS, LMS & BIM** *John Sayer, Johnson Controls, Senior Project Development Engineer*	**New Thermally Conductive Polycarbonate Materials for Heat Management in LED Lighting** *Axel Wetzchewald, Covestro, Marketing Manager*	**The Fifth Material - First Impression** Dr. Lars Meeß-Olsohn Leichtbaukunst, Architect
14.30	**New Outdoor Stable LED Technology Enables Cost Efficient and Compact Luminaire Designs** *Markus Hofmann* *OSRAM Opto Semiconductors, Senior Key Expert*	**How the OpenAIS Group Communication Allows Secure and Low Latency Interoperable IoT Based Lighting Controls Designs** *Giulio Borsoi, Zumtobel Group, Researcher*	**Innovation in Water Purification Systems with UVC LEDs and Silicone Optics** *Dr. Francois de Buyl* *Dow Corning, Adhesion Senior Specialist*	**The Role of the Lighting Project in a Multidisciplinary Design Process** Dr. Arch. Helena Gentili Politecnico di Milano, Adjunct Professor, Lighting Designer
15.00	**Latest Technology Updates of Modern OLEDs for Lighting Application** *Dr. Jörg Knipping* *OLEDWorks, R&D Manager*	**OS-NET, An Optimized Wireless Lighting Control Solution** *Andy Huang* *IR-TEC, Business Development Director*	**Smart Design of Freeform Micro-Optical Elements for Thin Direct Lit-Luminaires** *Dr. Christian Sommer, Joanneum Research, Deputy Head of Research Group*	**FORUM** **Design meets Technology - Architectural Lighting Design, Who does What?** *by APIL*
15.30	**Roll-to-Roll Solution Processed Flexible OLEDs from the PI-SCALE Open Access Pilot Line** *Prof. Pim Groen, Holst Centre, Professor*	**Miniaturization of LED Drivers** *Mickey Madsen* *Nordic Power Converters, CEO*	**Optimization of Free-Form Optics Using T-Splines in LED Illumination Design** *Annie Shalom Isaac* *Karlsruhe Institute of Technology, Researcher*	
16.00	COFFEE & LpS EXPO / TiL SHOW			
16.30				
17.00	Forum Grosser Saal		**Award Ceremony & Expert Panel Debate on the Future of Light**	
18.00 - 21.00	Get Together Evening Hauptbühne		**Networking, Live Music, Drinks & Food, Drinks & Food, Introduction to the Opera Carmen on the Floating Stage**	

LPS 2017 PROGRAM | SEPT 28TH

Time	System Quality Seestudio	System Qualification Saal Bodensee	Applications Propter Homines	Forum Seefoyer
08.00	**Towards the Digital Fabrication of LED Lighting Prototypes** *Dr. Daria Casciani* *Politecnico di Milano, Researcher, Designer*	**Spectroscopic and Oscilloscopic Studies of Commercial LED Bulbs and Their Flickering Measurements** *Dr. Aman Nagi* *University of Lucknow, Researcher*	**Special LED Lighting for Poultry Farms: Research and Extension** *Prof. Jinming Pan* *Zhejiang University, Professor*	**WORKSHOP** **Science meets Application** *by Luger Research & Scientific Partner Network*
08.30	**Lifetime- and Economic Efficiency Simulation of LED Luminaires** *Sebastian Hämmerle* *Vorarlberg University of Applied Sciences, Researcher*	**Impact of Spectrum and Color Temperature on Circadian Clock and Melatonin Suppression - Spectra Model and Installed Projects** *Luca Marinozzi* *Cariboni Lite - Fivep, Optics Developer*	**Standards and Design Guidelines on Artificial Lighting for Indoor Farming** *Henry Marvin Böll* *TÜV SÜD, Technical Manager Lighting*	
09.00	**Advanced Materials to Protect LED Systems from Degradation Caused by Sulphur and Halogens Based Contaminants** *Dr. Alessio Corazza* *SAES, BDM*	**Photorealistic Luminance Measurement Method and Homogeneity Analysis by Using Digital Cameras** *André Custódio* *Aspoeck, Optical Engineer*	**Challenges and First Practical Experiences of Roadway Lighting Design in Virtual Reality** *Viktor Zsellér* *Arrow, Application Engineer*	
09.30	**Quality Aspects and Standards in Horticultural Lighting** *Walter Parmiani* *UL, Principal Designated Engineer*	**Solid State Lighting Measurements - From Basics to Recent Developments** *Dr. Denan Konjhodzic* *Instrument Systems, Application Engineer*	**LED Lighting Systems for Indoor Horticultural Systems of the Future - inFarming** *Volkmar Keuter* *Fraunhofer-Institute, Head of Department Photonics and Environment*	**WORKSHOP** **Miniaturization of Solid State Lighting Systems** *by EPIC*
10.00	COFFEE & LpS EXPO / TiL SHOW			
10.30				
11.00	**Accelerated LED-Degradation under Exposure to Air Pollutants** *Dr. Michael Kunzer* *Fraunhofer, Group Leader LED Modules*	**The Importance of Accurately Modeling Light Scattering in Luminaire Design** *Dave Jacobsen* *Lambda Research, Senior Application Engineer*	**Towards Finding the Optimal Illumination Spectrum for a Particular Retail Scene** *Kaveh Ahmadian* *Light & Lighting Lab. KULEUVEN, Researcher*	
11.30	**Aerosol Jet Printing: A Promising Technology for LED Packaging** *Dr. Paul Hartmann* *Joanneum Research, Director*	**Lighting Quality Metrics - CIE and IES Recommendations on Flicker, Color Rendering and HCL** *Mikolaj Przybyla* *GL Optic, COO*	**LUMENTILE EU Project - Integration of SSL into Ceramic Tiles: A New Product for Smart-City Applications** *Dr. Luca Carraro* *University of Pavia, Project Manager*	
12.00	**Smart and Flexible Luminaire Production Solution** *Christian Stöhr* *Mühlbauer, LED Project Leader & Global Account Mgt.*	**Automatic Panel Level Transient Thermal Tester** *Prof. Gordon Elger* *Univ. of Applied Science Ingolstadt, Professor*		
12.30	LUNCH & LpS EXPO / TiL SHOW			
13.00	Forum Werkstattbühne		**Lighting Up the Dark Corners of the Internet of Things (IoT)** **Live IoT Hacking Demonstration** *by PenTestPartners*	
14.00	CLOSING, END			

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State of the Art

The rayfile is one of the most important light source models in ray tracing software [2]. It lists up several million or even more individual rays. Each ray is described by the starting position *x*, *y*, *z*, the direction *a*, *b*, *c* and a partial luminous or radiometric flux ϕ. Rayfiles are the results of the measurement of the light source in the nearfield.

The measurement is done with a nearfield goniophotometer [3] as visualized in figure 1. The different types of goniophotometers have in common, that there are at least two moving axes, which move either the device under test or an ILMD (Imaging Luminance Measurement Device) in angular space. The spatially resolved ILMD integrates the photons and reduces the n-dimensional spectrum to a one dimensional value for each pixel. The product of the lens' and optical filter's transmission function and the ILMD's responsivity function typically equals the V(λ) function describing the photometric sensitivity of the human eye. Due to the spectral integration of the ILMD there is no spectral resolved information available in such classic rayfiles.

If the ILMD would be replaced by a hyperspectral camera, the spectral information would remain available. However, the measurement time may be long due to the large number of spectral resolved measurements and a longer integration time, which may even lead to a start-stop operation [4, 5]. Also the system produces an extremely large amount of data - a spectrum for each pixel at each angular position - and the uncertainties of the reconstructed spectra are currently hard to predict [5].

Figure 1:
Conventional near field goniophotometer with two moving axes

Numbers of spectral/ ILMD/filter measurements	Global spectral measurement	Angular resolved spectral measurements
One ILMD/filter measurement	Spectral variations not accountable	PCA (Principal Component Analysis) method [5]
More ILMD/filter measurements	Sharp spectral separation (Blue/Yellow approach [7]) PMBS (this paper)	Polychromatic ray data [6], Spectral Adjusting towards chromaticity coordinates [4]

Table 1:
Concepts to add spectral information to rayfiles and allocated state of the art methods

Creation of spectral rayfiles with conventional goniophotometric measurements

As shown in table 1, Rykowsky summed up four different possibilities to combine spectral measurements and conventional goniophotometric measurements [4]. They differ in the amount and type of measurements and so in measurement time. While the options on the left hand side require only one spectral measurement, the options on the right hand side require time-consuming angular resolved spectral measurements. The row differs in the amount of goniophotometric measurements.

The upper left option of table 1 is not able to account any varying spectra and will therefore not be discussed further. The bottom right methods require angular resolved spectral measurements and different filter measurements. In [6] a larger number of ILMD measurements are combined with angular resolved spectral measurements. Rykowsky [4] describes a spectral adjusting of the angular resolved spectra to reconstruct measured chromaticity coordinates. However, both measurement time and the generated amount of data are higher compared to other methods.

Based on the upper right option, Jacobs et al. proposed a method, which is capable of producing angular resolved spectral rayfiles by performing a principal component analysis of the angular resolved spectra [5]. This method reduces the amount of memory used for the data. However, it can only be used if there are no significant spectral variations as a function of spatial dimension [4].

The remaining methods rely on one spectral measurement and more ILMD based measurements. An additional ILMD based measurement as used for the bottom left methods is typically much faster than an angular equally resolved spectral measurement.

A common example is the sharp spectral separation or blue/yellow approach [7], which is often used to describe the color variation of phosphor-converted white LEDs.

Blue/yellow rayfiles for phosphor converted white LEDs

The goniophotometric measurement has to be done twice; once with a blue and once with a yellow filter. Each rayfile contains a sharp separated global spectrum. The rayfiles have different spatial and angular resolved amplitudes for each global spectrum and in the end describe a varying spectrum. The measurement time is quite fast and the results are strongly improved compared to one global spectrum, which cannot describe any spectral varying information.

Figure 2a shows the spectrum of the main radiance direction of a neutral white LED (4000 K), which was created based on a measured blue/yellow rayfile. Besides the small discontinuity at approx. 520 nm, the simulated spectrum seems to look physically correct compared to the measurement of the identical LED. The sharp spectra in figure 2b are the global spectra of the blue/yellow rayfile and their associated chromaticity coordinates, which define the blue/yellow mixing line in figure 2c. The ratio of the blue/yellow rayfiles is able to shift the chromaticity along the line. The small misalignment between the blue/yellow line and the line of the measured spectra is due to the difference of the sharp global spectra from the real physical basis spectra of LED and phosphor. This methodical inaccuracy is also the reason for the discontinuity of the simulated spectrum in figure 2a.

The absolute impact of this methodical error depends on the degree of spectral overlap of the true physical basis spectra. If the overlap is stronger, the error gets larger. That is also the reason for the limitation of the sharp spectral method to classic blue/yellow LEDs.

Physical Motivated Basis Spectra (PMBS)

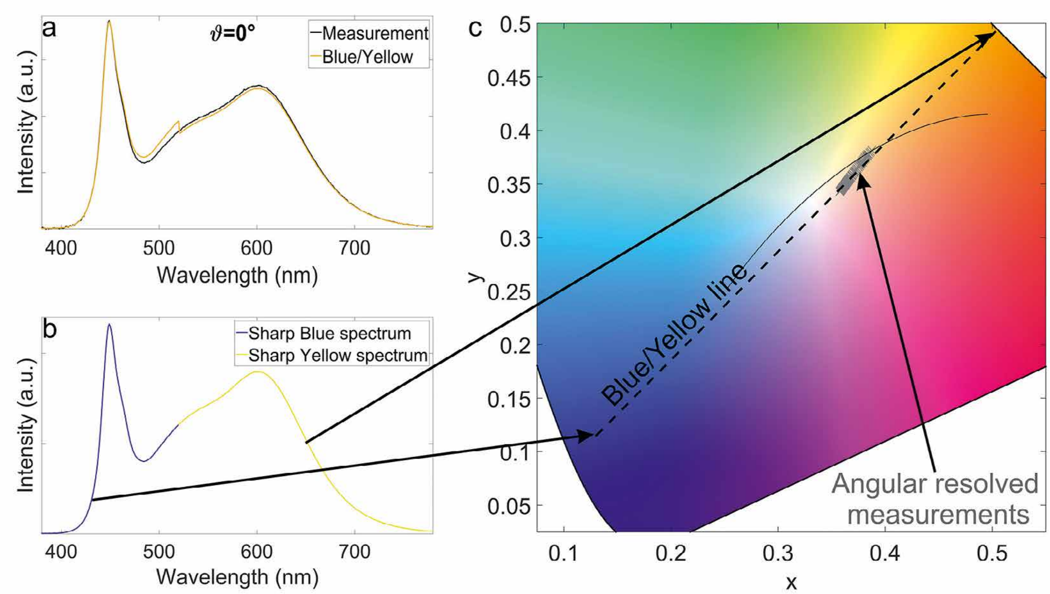
Based on the start-of-the-art, the requirements for a measurement technique, which is able to generate spectral rayfiles of LEDs can be summarized.

Measurement technique requirements to generate spectral rayfiles:

- Short measurement time
- Generally applicable (for instance not limited to blue/yellow)
- Easy to implement without additional hardware investments
- Angular and spatial resolved spectral information
- Spectral accuracy to allow colorimetric/spectral simulations with realistic predictions

Concept and spectral separation

Our concept is basically an extension of the constant basis spectra approach from Jacobs et al. and the blue/yellow approach and also belongs to bottom left of table 1. Our main assumption is that each varying LED ray *R*, which depends on the spatial position *x*, *y*, *z* and the angular direction θ, Φ can be described as weighted sum of its



Figures 2a-c: Blue/yellow - reconstructed spectrum (a) at main radiance direction (θ = 0°), global blue/yellow spectra (b), and their associated mixing line in the chromaticity diagram (c) underlying constant basis spectra $S(\lambda)$ as shown in EQ 1.

$$R(x,y,z,\theta,\phi,\lambda) = \sum_{i=1}^{N} A_i\,(x,y,z,\theta,\phi)\cdot S_i(\lambda) \quad (1)$$

Since the relative spectral distribution depends on the physical origin, only their relative amplitudes remain as a function of angular and spatial dimension. This assumption is true if the system is in steady state condition and if nonlinear effects as self-absorption or saturation of the phosphor are negligible.

If the individual physical basis spectra are not available, the basis spectra can be approximated quite well, based on at least one spectral measurement of the whole spectrum $R(\lambda)$. There are advanced phenomenological LED models, which can be used to model all LED basis spectra [8]. The remaining phosphor spectrum can be modeled as smoothed spline. Their general correctness can be tested by a comparison with additional individual spectral measurements at random angular positions.

Spectral reconstruction

During a goniophotometric measurement, the transmission function τ_1 of the filter is multiplied with all weighted basis spectra $A{\cdot}S(\lambda)$ and then integrated by the ILMD. This results in the measurement value M_1 for each camera pixel and each angular position as displayed in EQ 2. The variable $\tau_{Sys}(\lambda)$ includes all remaining transmission and responsivity functions, for instance those of the ILMD, lens or neutral density filters.

$$M_1 = A_1 \int S_1(\lambda)\,\tau_1(\lambda)\,\tau_{Sys}(\lambda)\,d\lambda + \ldots + An \int S_n(\lambda)\,\tau_1(\lambda)\,\tau Sys(\lambda)\,d\lambda \quad (2)$$

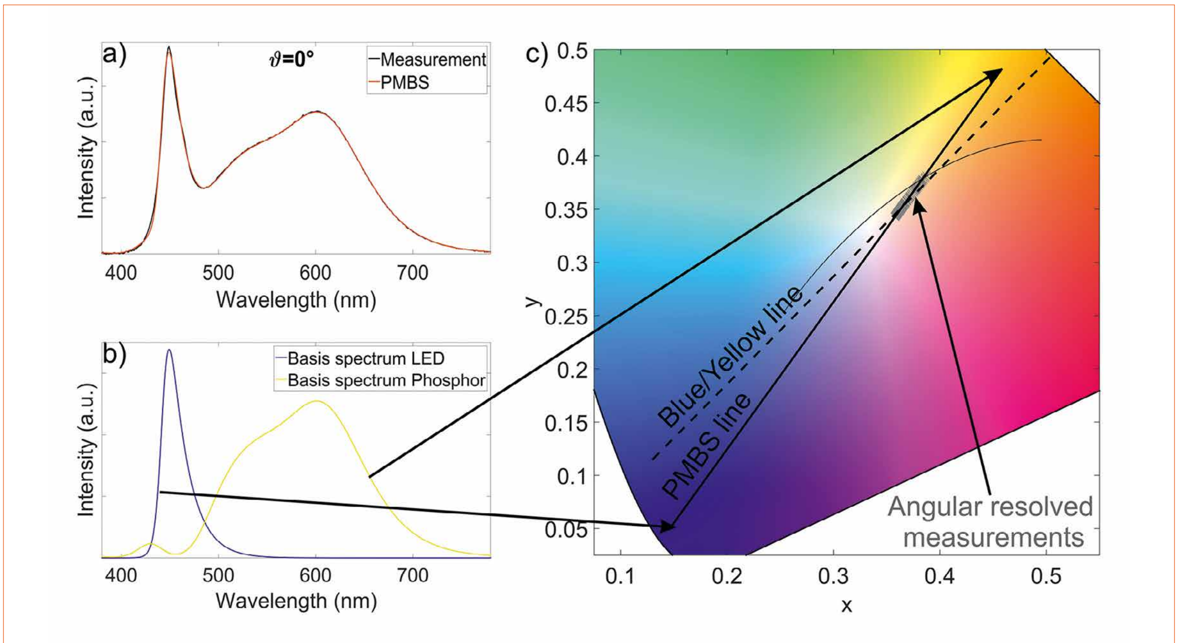
Additional goniophotometric measurements with other transmission filters τi(λ) result in additional measurement values Mi. All equations or rather goniophotometric measurements therefore lead to a system of linear equations, in which everything besides the weighting factors Ai is known. The system is rewritten in its matrix form in EQ 3.

The system of linear equation can be solved if the number of measurement values equals the number of unknown amplitudes, which is the number of basis spectra. In case of a blue/yellow LED two measurements are required. If an additional red LED is added the necessary amount of measurements increases to three. If there are enough measurements, the system can be solved by inverting the matrix, which contains the integrated spectral information and a multiplication with the measurement vector. Finally, the combination of the basis spectra and the amplitudes creates the desired spectral rayfile.

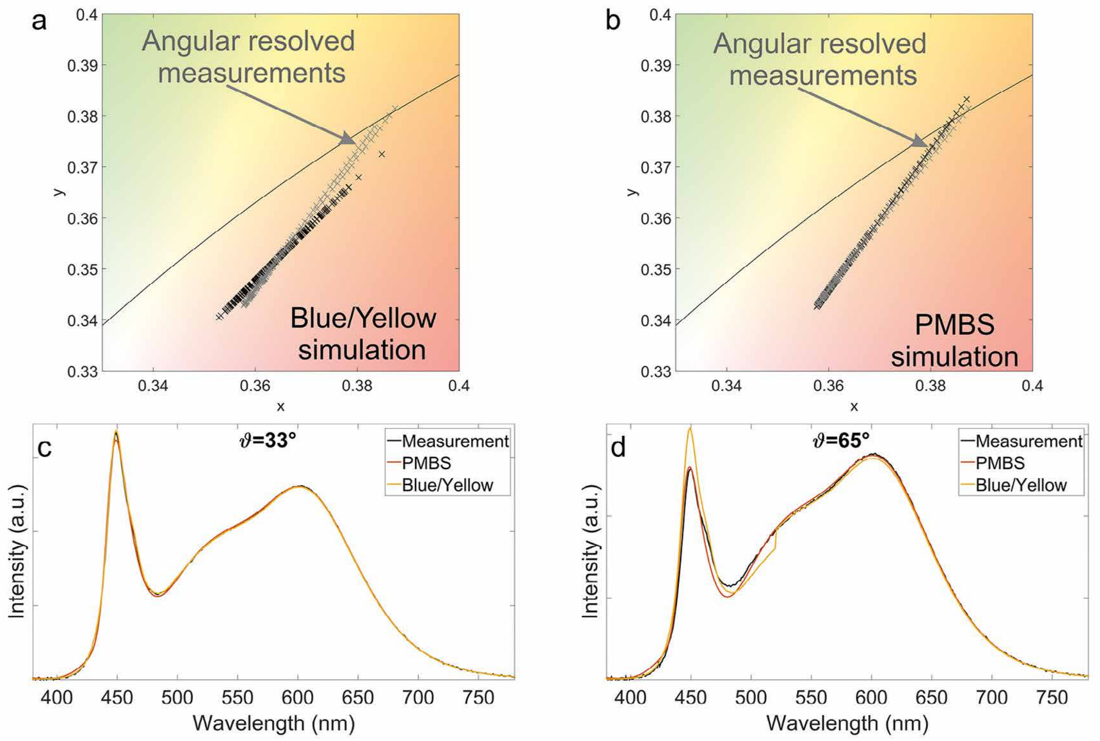
Evaluation of the PMBS method

To prove the potential of the PMBS method we reconstructed and evaluated the spectra of the 4000 K LED. The main radiance direction is visualized in figure 3a. Therefore we used two filter measurements with the off-the-shelf filters $X_{Short}(\lambda)$ and $X_{Long}(\lambda)$ and the separated basis spectra of figure 3b. Both rayfiles are recalculated based on EQ 3.

$$\begin{bmatrix} M_1 \\ \vdots \\ M_n \end{bmatrix} = \begin{bmatrix} \int S_1(\lambda)\,\tau_1(\lambda)\,\tau_{Sys}(\lambda)\,d\lambda & \cdots & \int S_n(\lambda)\,\tau_1(\lambda)\,\tau_{Sys}(\lambda)\,d\lambda \\ \vdots & \ddots & \vdots \\ \int S_1(\lambda)\,\tau_n(\lambda)\,\tau_{Sys}(\lambda)\,d\lambda & \cdots & \int S_n(\lambda)\,\tau_n(\lambda)\,\tau_{Sys}(\lambda)\,d\lambda \end{bmatrix} \cdot \begin{bmatrix} A_1 \\ \vdots \\ A_n \end{bmatrix} \quad (3)$$



Figures 3a-c: PMBS: Reconstructed spectrum (a) at main radiance direction (θ = 0°), global basis spectra (b) after spectral separation, and their associated mixing line in the chromaticity diagram (c)



Figures 4a-d: Comparison of blue/yellow, PMBS and measurement - chromaticity coordinates of the blue/yellow and measurement (a), Chromaticity coordinates of the blue/yellow and measurement (b), simulated and measured spectra at $\theta = 33°$ (c), and simulated and measured spectra at $\theta = 65°$ (d)

Figures 4a&b show the chromaticity coordinates, which results from the blue/yellow and PMBS simulations compared to the measurement data in the chromaticity diagram. Due to the much better alignment of the PMBS line (Figure 3c) with the measurement data, the mean chromaticity distance of the simulation is only $\Delta xy = 2 \cdot 10^{-3}$ respectively $\Delta u'v' = 1 \cdot 10^{-3}$, which is below the region of just noticeable color differences [9]. Figures 4c&d show reconstructed and measured spectra. At the angle $\theta = 33°$, the blue/yellow approach is slightly better than the PMBS method, since the spectrum at this angle was used to determine the sharp global blue/yellow spectra. However, at an angle of approximately $\theta = 65°$ the PMBS spectrum is more accurate.

Conclusions

There are measurement techniques, which are capable of generating spectral rayfiles with conventional measurement technology. However, there is often a trade-off between accuracy, applicability and measurement time. We proposed the physical motivated basis spectra (PMBS) approach, which minimizes the measurement amount with respect to the device under test. Most important, PMBS is a general approach. If, for instance, a red LED is added to a blue/yellow spectrum, which might, for example, be necessary to increase the color rendering index, a sharp spectral separation would create large errors. The PMBS method can be used without further restrictions. If PMBS is applied to white phosphor converted LED and compared to the most used state of the art technique, which was specially designed for those LEDs, our results are more accurate. ■

Acknowledgement:
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References:
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[2] R. Dürr and U. Streppel, “Rayfiles for non-sequential raytracing,” International Light Simulation Symposium ILSIS, Nuremberg, Germany, 11-24(2012)
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[4] R. Rykowski, “Spectral ray tracing from near field goniophotometer measurements”, Light Eng. 19(1), 23-29, 2011
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[6] D. Hansen, S. Paul, and V. Schumacher “LED Measurement to Obtain Polychromatic Raydata and their Value for Simulations”, LpS 2012, Bregenz, Austria (2012)
[7] Osram Opto Semiconductors Application Note, “Importing rayfiles of LEDs from OSRAM Opto Semiconductors”, 2013
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Challenges when Designing LED-Based Illumination Systems in Medical Applications and Diagnostics

LEDs have become indispensable in medical technology and dentistry. But the requirements placed on these lighting products are very high: Minimized size, high, application specific color rendering index, efficient temperature management, usability and excellent disinfection opportunities are all extremely important. Prof. Paola Belloni from the Steinbeis Transfer Center Illumination Optics and Lighting Engineering and Furtwangen University, and Alexander Gärtner from the Faculty of Mechanical and Medical Engineering of the Furtwangen University discuss the requirements for different applications such as endoscopy, surgeries, dental devices, and photodynamic therapy. Further topics are the development of a self-disinfecting operation interface with edge-lit UV-A LEDs, and a new optimization approach, taking into account the reflection and absorption properties of human tissues.

An increased demand for minimally invasive treatments and a better understanding of photobiology has led to a growing interest in LED-based therapies. The clinical applications of red, yellow, blue, UV and near infrared (IR) LEDs include wound healing, acne treatment, sunburn prevention, phototherapy for facial rhytides, and skin rejuvenation [1]. All these LED-based therapies rely on the principle that electromagnetic radiation of different wavelengths triggers the healing process by means of the biological effects of radiation on the human body. Below we report on a recently started project of a photobiomodulation treatment in which an LED-based device will be designed for in-vitro wound healing applications.

However, hereafter, this article focusses on the development challenges of LED-based medical devices. The development is driven by the requirement of adequate in-situ illumination for correct positioning and operation of the medical device. Traditionally xenon, halogen and metal halide lamps have been used as surgical light sources because of their high luminance and color rendering index ($Ra \geq 95$). These lamps emit over a broad spectrum across the visible range and can provide a colour close to daylight. Usually, the incorporation of various filters in order to attenuate unwanted wavelengths directly in front of the light source is required. However, a conventional lighting environment produces a lot of heat leading to the waste of energy and a short lifetime.

Currently, LEDs are systematically replacing Xenon lamps in medical devices because they are energy-efficient, small, durable, less expensive and their spectral emission in the visible range can be tuned. In fact, a natural color reproduction of the tissue or the tissue contrast is becoming more important for medical diagnostics. Optical properties of biological tissue vary widely depending on the tissue type that may be highly reflective (fat), highly absorptive of blue/green light (blood) or may have fluorescent properties (collagen) [2]. Therefore, using LEDs as light sources allows developing multifunctional illumination units which spectral characteristics can be flexibly adapted to the specific diagnostic procedures.

Spectrally Tuned Illumination Units for Color and Contrast Enhancement

In medicine recognition of red color is essential for diagnosis and surgical treatment. There is a general agreement that standard lamps used during medical procedures have to meet the requirements of high values of general colour rendering index (Ra) and specific colour rendering index for sample 9 (R9) exceeding 92.

Moreover, in photodynamic diagnosis blue light is used for excitation of fluorophores to aid visualization of tumours [3] whereas narrowband imaging with helps to increase tissue contrast and therefore the visibility of the vasculature [4]. The spectral output of multileds sources may be tuned to any colour in a triangular region of the chromaticity diagram CIE and includes white light of varying colour temperature and can be adjusted to match a number of standard illuminants including daylight and Xenon. When used with a white-balanced video camera the output of this multileds source provided white light at a similar imaging quality to the standard Xenon sources (Clancy et al [5]).

A description of tuneable LED-based light sources optimized for color and contrast enhancement of tissues as well as validated in medical diagnostics follow.

Clancy et al. [5] described an homogenized LED light source made up of four ultrabright LEDs in the red, green, blue and violet (λ < 430 nm) spectral regions. A light pipe multiplexer combines light from each of the four LEDs and couple it efficiently into the optical fibre bundle using dielectric thin-film optical coatings. The LED light source is coupled to a standard endoscope and color contrast on ex vivo tissues analised.

Blaszczak et al. [6] constructed a tuneable LED-based multi-emitter source made up out of 13 LEDs which allowed adjusting the correlated colour temperature. Correlated colour temperature of this LED set can vary from 2700 K to 6500 K and the colour rendering indexes are not lower than 93 (Ra>97 R9>98, R1-R14>93). Different shapes and sizes of mixing optical elements were first calculated and then verified with a prototype to optimise the quality of colour mixing.

A commercial device recently available [7] has focussed on providing high contrast in the tissues by shifting the spectral properties of the LED sources (Figure 1).

In the Spectra mode of the Video-Uretero-Renoscope FLEX-Xc of Karl Storz, the bright red portions of the visible spectrum are filtered out and the remaining color portions are expanded to allow recognition of the finest tissues. Additionally, the Chroma mode intensifies the color contrast in the image. Clearly visible structure surfaces are emphasised while retaining the color perception in the image.

LED-Based Endoscopy: State of the Art and Innovative Future Solutions

Endoscopic surgery has become an extremely significant process in today's medical diagnostic and therapy. The internal organs in the human body form a plurality of inner surfaces which can be investigated with the aid of an endoscope. Most lesions such as cancer or altered blood vessels start from the epithelial tissue which lies on the surface of the organs [2].

Even nowadays, most endoscopic video processors in clinical use still have Xenon lamps as cold light sources.

LED-based endoscopic illumination devices have been shown to have several benefits over the traditionally used Xenon lamp systems. However, their use in endoscopy has been initially limited by the difficulty to couple enough light into the endoscopic light cable efficiently. In fact, light from a source with a large angular Lambertian intensity profile must be matched to the small numerical aperture of a light guide or fibre bundle. The coupling efficiency can be significantly improved by a collimating lens inserted between the LED and the fiber end [8].

Up to now, the actual light source is outside the endoscope in an external unit. The light is transported by means of total reflection through a fibre-optics cable to the endoscope end. This leads of course to a cumbersome handling of the medical device. Therefore, it would be a much better solution to

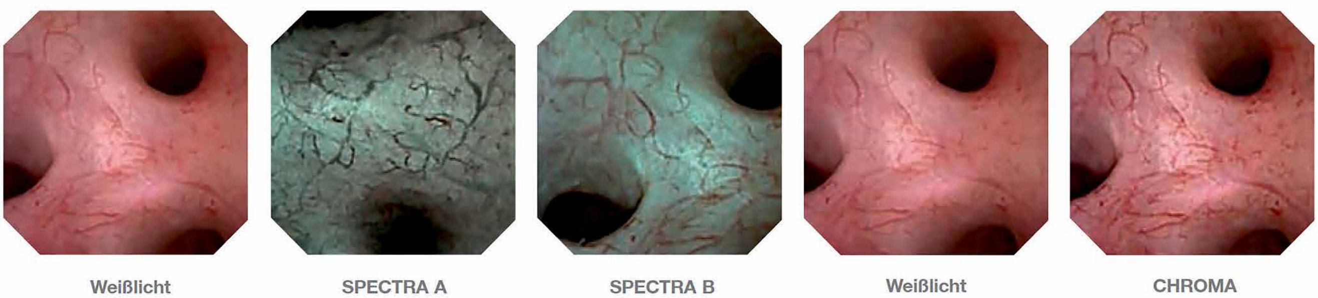


Figure 1: The simultaneous display of a white light image and an image in the visualization mode (Chroma, Spectra) enables a direct comparison of tissue structures on the monitor during surgery and thus facilitates the diagnosis

integrate the LED light source into the endoscope itself, by placing it either in its handle or its tip.

Both technical possibilities present challenges with respect to heat dissipation in order to be compliant with the strict regulations regarding temperatures and electrical safety of medical equipment as defined in the European normative DIN EN 60601 [9].

When mounting LEDs in the handle, the generated light has to be transported to the surgical field via fibre optics. As already mentioned above, additional optical components are necessary to avoid substantial losses when coupling LED light into fiber optics. Unfortunately, the spacial constraints imposed by the handle geometry are less favourable than those in an external light box. Recently KARL STORZ introduced an Uretero-Renoscope with LEDs integrated in the handle [7].

When integrating LEDs into the tip of the endoscope, the entire luminous flux is available for illumination of the surgical site. However, it is necessary to transfer heat to the endoscope's handle in order to avoid overheating of the tip. Its minute size does not support thermal dissipation towards the surroundings. Moreover, DIN EN 60601 requires lower maximum temperatures for metallical device components that become in contact with human tissues compared to components that do not.

Brügemann [10] analysed the LED-integration on the endoscope tip and proposed to incorporate heat pipes to avoid overheating. Measurements of his prototype looked promising and proved compliant with DIN EN 60601.

The future of LED based endoscopy seems to be bright, but yet serious research efforts needs to be focused on improving the light coupling between reflected light from inspecting tissue and CCD of the camera, the electrical to light power conversion efficiency and the homogeneity of the illumination.

EDISON- Project

Endoscopy Illumination System Endoscopy Illumination System Optimization (EDISON) is one of the ten new projects in the research frame work initiative CoHMed (Connected Health in Medical Mountains) aimed at transferring current scientific trends in medical technology to biologize, miniaturize, and digitalize medical devices with industrial partners of the University of Furtwangen. EDISON´s main goal is to improve light guides in rigid endoscopes by increasing the efficiency of the illumination unit and the uniformity of the illuminated area. First, the spectral properties and angular distribution of LED light sources and fibre optics are optically simulated with LightTools (Synopsys©). Those findings will be experimentally validated with measurements of prototypes in the lighting laboratory (Figure 2).

Moreover, critical issues in the light transport and coupling inside the endoscope device itself will be identified:

- Shape and dimension of the coupling interface (i.e. glass condensing cone)
- Entrance and exit angles of light at the interfaces (α,β)
- Dispersive losses in the fibers optics and in all other optical components

Optimization results will be systematically fed back into the development process, resulting in new prototypes with improved light guides and coupling units.

Measurements of the typical efficiency of state of the art rigid endoscopes powered by LED light sources - defined as a ratio between

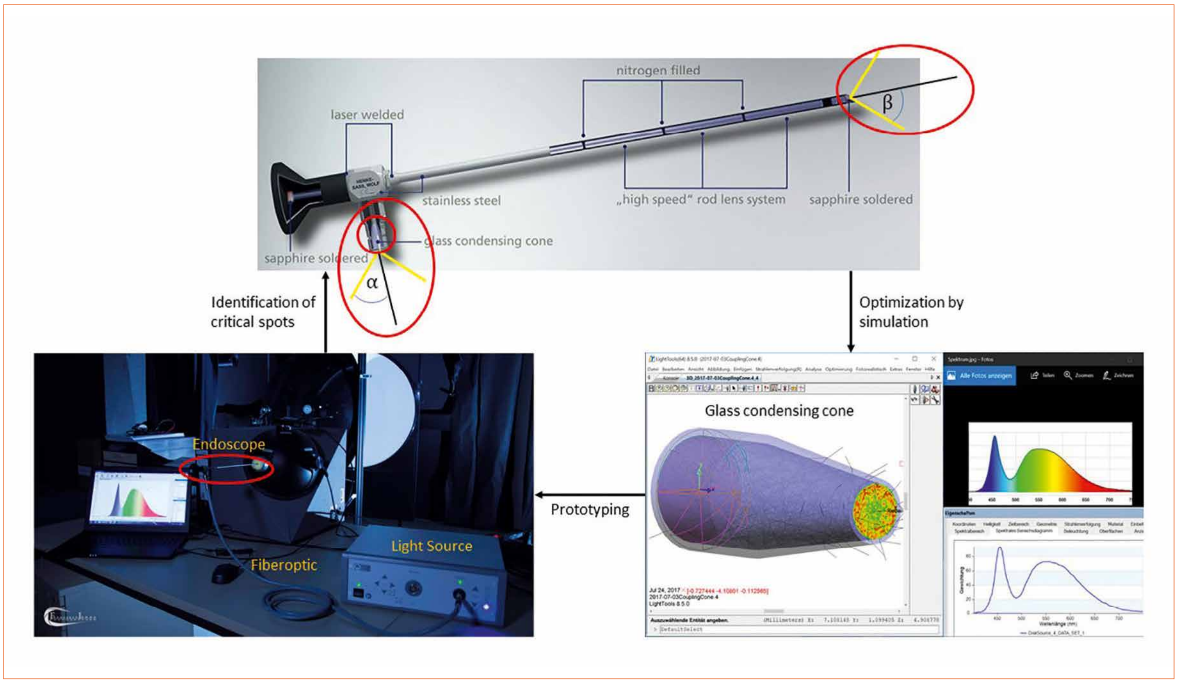


Figure 2: Schematic description of the development process. A rigid endoscope with critical spots for radiation losses, the equipment of the lighting laboratory used during the analysis of the light source and endoscopic device, example of optical simulations

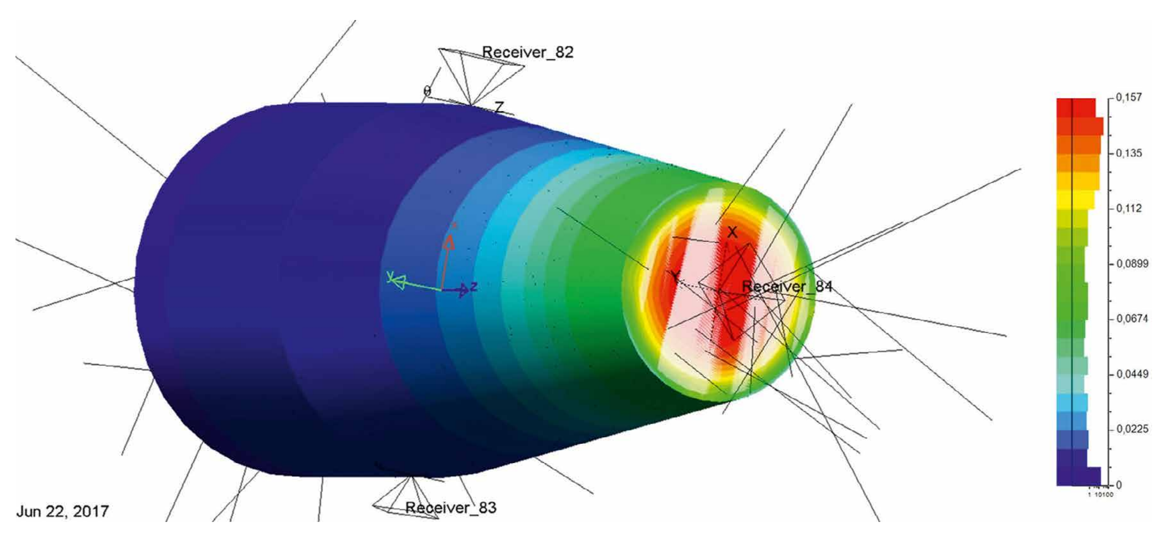
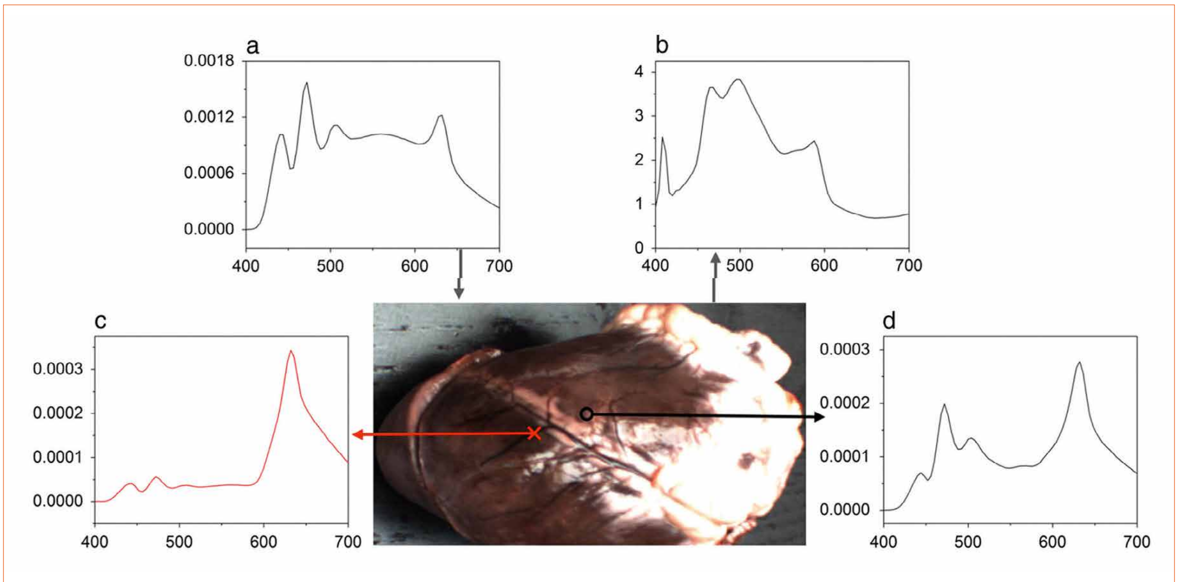


Figure 3: Optical simulation of light coupling from a fiber bundle into the glass condensing cone of the endoscope. The receivers placed on the surface of the condensing cone show the regions in which most of the radiation losses occur (green color)



Figures 4a-d: Images of specimens were obtained using a charge-coupled device (CCD) camera and before the experiments the camera and the PR655 SpectralScan spectrometer were all calibrated with the D65 standard light source. Spectral radiance of incident light (a). Spectral reflectance of fresh ovine blood obtained with a spectrometer (c). Spectral reflectance of ovine myocardium background tissue (d). Spectral reflectance contrast - *C(λ)* - of blood and background myocardium tissue (b). Tissues illuminated with wavelengths between 450 and 550 nm will have a strong gray contrast in the display image, which will help the surgeon easily identify them (from Clancy et al. [5])

luminous flux out of the endoscope relative to the fiber optics one - confirmed a very low value of approximatly 35 %. The first optical simulations clearly show that the glas condensing cone is crucial for light intensity losses and that the coupling efficiency is strongly dependent on the angular distribution of the fibre optics light input (Figure 3).

A further EDISON goal is to develop a spectral composition for the LED-source that will offer the best specific contrast between the surgeon's area of interest (tissue with suspicious pigmentation, appearance, texture, color, …) and surrounding tissues which can in a sense be considered as background (or normal). Therefore, the specific reflection properties of theses different areas have to be considered in the optimisation of the light source as only reflected light is usable for the surgeon. Systematic measurements of angle dependent reflection and transmission properties of representative human tissue samples are planned.

The advantage of a spectral reflectance comparison model has been shown by Shen et al. [11] and will be briefly described here. They focussed on searching for the wavelengths which produce the highest contrast between blood vessels and background tissues. An LED-based ceiling system made up of 11 high power LEDs, consisting itself of eight color LEDs and three white LEDs with different correlated color temperatures (CCTs) was used as light source. The intensity level of each LED could be controlled and software was developed to generate the target source spectral distribution.

The spectral reflectance contrast $C(\lambda)$ is defined as

$$C(\lambda) = R_m(\lambda)/R_b(\lambda)$$

where R_m and R_b are the spectral reflectance spectra of blood and background tissue.

To verify the accuracy and stability of this method an ovine heart was set and imaged (Figures 4a-d). The $C(\lambda)$ (Figure 4b), implies that the spectral components between 450 and 550 nm contribute the most to the identification of blood vessels that have a meat background.

The presented results showed that images obtained with an optimized spectrum had a higher contrast than those obtained with a commercial white light even if different color temperatures were used.

UVA-LED Applications

Recent improvements in flux density, stability and life hours of UV-LEDs have made them a viable solution for replacing traditional UV light sources such as mercury lamps, Xenon lamps, hot and cold cathode lamps. The applications vary from curing, counterfeit detection and digital printing (UVA), phototherapy (UVB) and disinfection/purification (UVC). Below we report on two optical development projects conducted with industrial partners over the last 3 years. The motivation was either to integrate UVA LEDs in existing products or to enable new applications previously not feasible with conventional UVA lamps.
One of the main challenges was identifying suitable UVA LEDs among the very few reliable products which had the required power output and optomechanical characteristics. In the meantime the availaibilty of high power UVA LEDs, even in the deep UVA, has rapidly increased, since more companies have entered this market. Therefore we believe that most of the problems we faced could be now successfully solved.

Optical design of a self-disinfecting operation interface

Disinfection of surfaces is necessary in biological laboratories and medical facilities to reduce the risk of contamination or decease contagion. Bacteria and germs on the glass surface coated with TiO_2 can be oxidized with sufficient UV exposure. Many studies suggest that the photocatalytical effect of TiO_2 can be triggered with much longer and easier-achievable wavelengths, i.e. UVA, and with an overall lower intensity dosage, compared to the UVC-disinfection. The system can thus be strongly antimicrobial [12]. Based on this principle, we developed an active self-cleaning touch-system with a glass surface and several integrated UVA LEDs for applications like a nurse-on-call system.
We used UV-LED light sources with a central wavelength of 375 nm, FWHM of 11 nm and 320 mW power output (Seoul Optodevice).

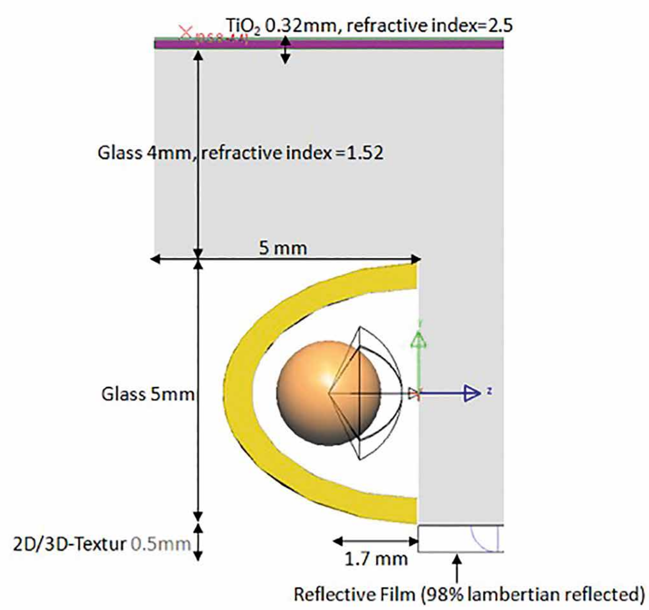


Figure 5:
System of the described self-disinfecting operation interface showing the glass panel with the TiO_2 coating

For the concrete product application, there were some boundary conditions:

- Minimum UVA intensity reaching the TiO_2-coating greater than 3 mW/cm^2 (trigger threshold for free ions in the semiconductor)
- Continuous UVA irradiation covering the whole display area with sufficient homogeneity
- No additional cover/frame around the glass panel
- Light source invisible to user

Behind the glass panel there is a normal printed circuit board with several layers such as design, resin, copper and solder resist and none of these layers is UV-transparent. Therefore, as figure 5 shows, we constructed our system as a modified back-lighting model with the following components: Sideways-coupled light sources (hidden on the edge), a light guide, 3D extraction textures on the bottom of the light guide and a UVA reflective diffuser layer.

Figure 5 shows the glass panel and a thin TiO_2 coating with a refractive index of 2.5 positioned directly on its top surface. Eight LEDs are coupled in, four on each short edge. The glass is defined as a whole body with a refractive index of 1.52 at 375 nm. The 3D extraction textures zone is located on the bottom side of the glass to improve the uniformity of light extraction. Additionally, a very thin UVA reflective film with a Lambertian distribution is placed directly below the 3D extraction textures to simulate the white coating of the electrical board beneath the touch screen and to increase light scattering.

A prototype with 3D-laser extraction textures was produced and measured. The homogeneity of UVA irradiation distribution on the TiO_2 coated surface matched the optical simulations, but the irradiance values were lower than predicted and less than the required photocatalytical threshold of 3 mW/cm^2. The intensity losses were caused by the white coating, that was absorbing UVA. Therefore,

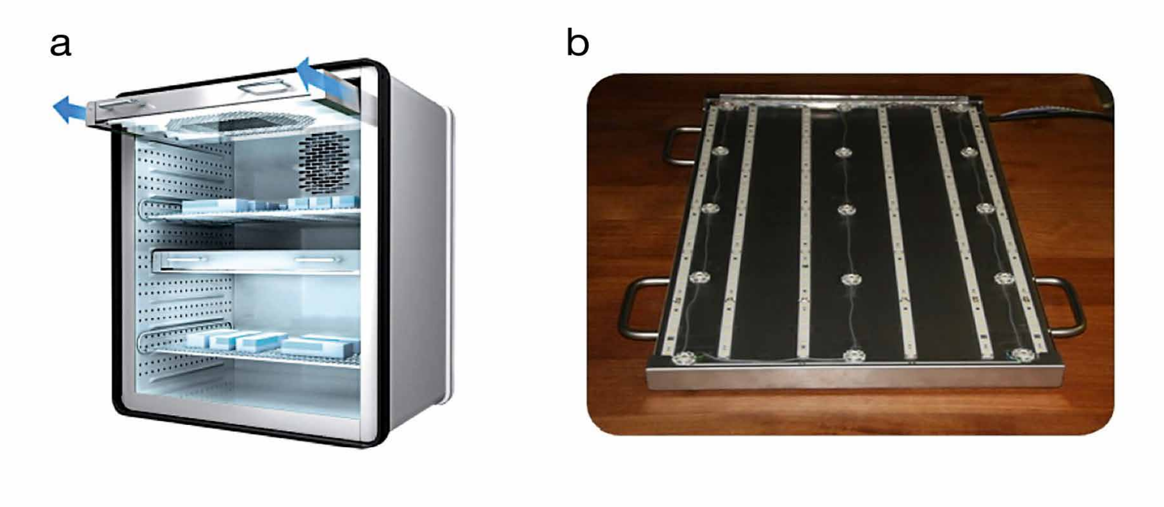


Figure 6a&b: Constant climate chamber (a) for photostability tests of the company Binder showing a flexible positionable light module traditionally equipped with fluorescent lamp. The prototype (b) equipped with 15 UVA LEDs uniformly distributed (0.9 W) and 8 cool white LEDs strips horizontally and vertically distributed (6300 lm)

we investigated different white coatings with higher reflectivity in the UVA range, but no satisfactory alternative was found.

Of course the critical threshold could have been reached using:

- More UVA-LEDs, increasing the costs of the self-disinfecting touch screen device
- LEDs in deeper UVA range, which were not yet available

Spectral distribution (ICH Q1B Option2)	Illuminance/irradiance	Uniformity
Broad band similar to cool white fluorescent lamp	> 7500 lx	Visible = ±10%,
+ UVA-range from 320 nm to 400 nm with intensity peak between 350-370 nm	> 1,4 Watt/m²	UVA = ±10%

Table 1: Development requirements for the new light module. Illuminance/irradiance and uniformity values are given for a distance of 12 cm from the light sources. The uniformity values refer to the mean value on a 350x500 mm area, which represent the usable surface area of the climate chamber for materials tests

Design and development of a light module for constant climate chambers

Climate chambers are used to test the effects of specified environmental conditions like extreme temperature, moisture or relative humidity, electromagnetic radiation, exposure to sun etc. on biological items and materials. In a constant climate chamber for photostability tests the light module has been traditionally equipped with fluorescent lamps to provide intensity and spectral distribution according to to the guideline ICH Q1B [13]. This guideline defines the photostability test conditions for new drugs and products by requiring exposure times of 1.2 Million lux hours in the visible and 200 Watt-hours/m^2 in UVA-range. Moreover, the guideline specifies the type of visible and UVA spectral light distribution to be used and on of the options allows the simultaneous exposure to a cool white fluorescent and a near ultraviolet lamp light.

The substitution of fluorescent lamps with LEDs presents some advantages:

- More space for test materials in the climate chamber due to smaller size of LEDs
- Less weight
- Longer lifetime of the light module

Therefore we started a feasibility study with the goal to design and develop a new opto-mechanical light module equipped only with LED light sources in both visible and UVA-range. The German company Binder [14] made available a climate chamber for photostability tests allowing us to test our development results in realistic conditions.

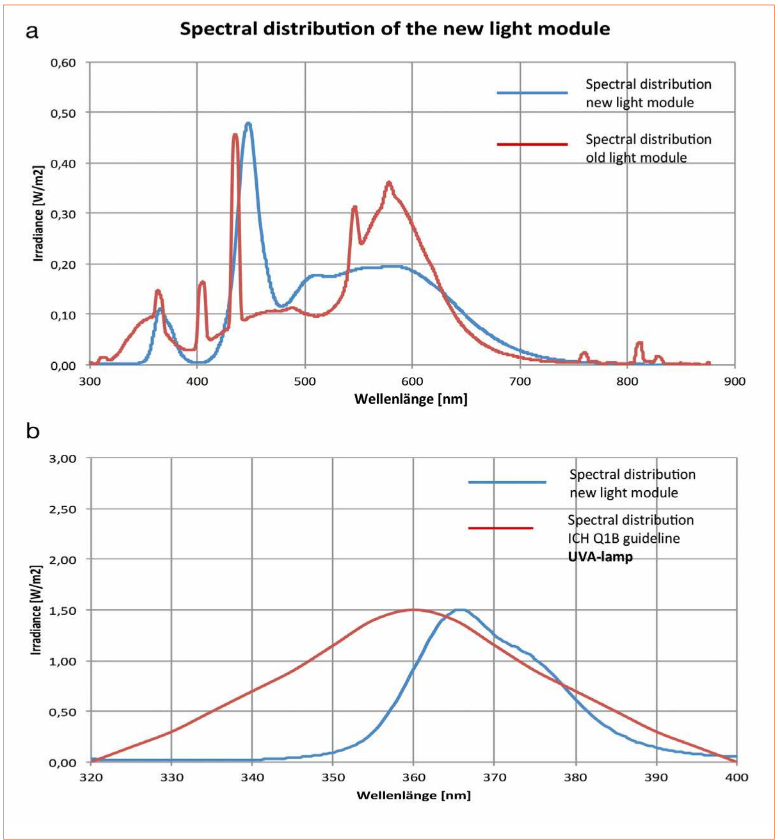
For the optical design and development of an LED-based light module for the climate chamber, we derived constraints on the LEDs spectral distribution, Power/Lumen package, Lifetime (ideally 50,000 hours for both visible and UVA components) and compatibility to both humidity (> 80%) and temperature conditions(up to 70°C).

In the visible range we used strips of low power LEDs (CCT = 6000 K) with lambertian angular distribution without secondary optics (870 lm per 500 mm LED strip). Only two UVA-LEDs were found to be acceptable despite not optimal electro-optical characteristics. The optical characteristics of the finally selected LED are a power output of 60 mW, a peak wavelength λp = 365 nm with a 20 nm FWHM, and a lifetime of only 10,000 hours (Seoul Optodevice). Its mechanical characteristics allowed it to be easily integrate into the circuit board.

The spatial distribution of UVA and cool white LEDs was optimised with respect to illuminance, irradiance and uniformity targets (Table 1) using the minimum amount of LEDs. To improve the uniformity of light extraction, we added 3D spherical extraction textures i.e.holes with a fixed radius of 0,5 mm to the front glas surface of the light module and calculated their best density.

The prototype (Figure 6b) was designed and made to be compatible with the mechanical

Figures 7a&b: Comparison between the spectral distribution of the new LED light module and the old one, showing overall a good agreement in the visible range (a). Zoom of the UVA spectral range from 320 nm to 400 nm showing an emission peak between 350-370 nm but not enough radiation in the 320-360 nm region (b)



As a light-based medical therapy PBM is employed to influence chronic wound healing processes [16]. A common issue found in PBM studies is lack of repeatability dueto inaccurate reporting or incorrect controlling of light irradiation parameters and measurement techniques.

The device consists of a LED module installed on cell culture trays capable of functioning inside an incubator without disrupting its normal operation. Light wavelength can be modified by altering the relative light intensity settings for different groups of LEDs with different emission characteristics in the visible range. The first prototype was realised with RGB LEDs with peak wavelengths at 632 nm, 523 nm and 465 nm and FWHM between 18 nm and 33 nm. Moreover, the uniformity of the irradiance field at the cell culture tray surface is crucial. Therefore, the LEDs spacial distribution is optimised by means of optical simulations.

The LED module can be programmed for multiple-week-long experiments with complex treatment schedules through a GUI or configuration file which allows for automated operation.

Finally, the device will be employed in a 21-day long treatment pilot study with an in vitro 3D organotypic tissue wound mode. ■

constraints of the climate chamber. The irradiance and illuminancevalues measured as well as their uniformity showed a very good agreement with the optical simulation results [15].

Despite the overall positive results, one issue must be further addressed. Due to their narrow band emission, the UVA-LEDs selected emit very little radiation below 355 nm. This can be seen as an argument against their use in climate chambers for photostability tests because the light sources must have a significant emission above 320 nm according to the current guideline ICH Q1B (Figures 7a&b). But in the meantime, some deep UVA LEDs in the range 320-350 nm have become available and could be additionally used in the light module to fill the irradiance gap below 355 nm. An additional major development constraint for a solely LED-based light module was the 10000 hours lifetime of the UVA LEDs. This is currently being improved, given the increased demand for long life UVA LEDs.

LED-Based Illumination Unit for Photobiomodulation in Vitro Studies for Wound Healing

The purpose of the CoHMed project Wound Healing is to design, construct and validate an automated device for performing repeatable in vitro LED- based Photobiomodulation (PBM) studies.

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Intelligent Lighting Designs Enabled by Laser Light

In many applications, solid-state lasers would be the best technical solution but until recently the costs were much too high. Nevertheless, this technology had its niches and is broadening the field of applications entering different specialty lighting, display, and automotive applications. Julian A. Carey, Product Marketing Manager, and Dr. Paul Rudy, Co-Founder & SVP of Soraa Lasers describe and explain the technology, applications and benefits of laser diode pumped phosphor sources that are, for example, used in high-end automotive headlights of luxury cars.

In many lighting applications it is valuable to utilize a high luminance light source with a high number of lumens emitting from a very small physical source extent. High luminance illumination sources provide increased levels of light intensity and smaller beam angles, and also precise control of beam properties. To date, conventional light sources that have been applied to advanced lighting designs have included high intensity discharge (HID), halogen lamps and high brightness light emitting diodes (LED). These sources have limitations in reliability, form factor and luminance. A new solid state lighting technology platform has emerged, laser light, enabling highly reliable, very small form factor light sources, with the highest luminance ever demonstrated in a commercialized product. An overview of how laser light is implemented and how various applications may benefit from increased performance from its use are presented.

Figure 1: Examples of architectural spotlights

Introduction

Specialty lighting applications that make use of very tight beam angles include entertainment and architectural lighting and are some of the most established users of halogen and HID light sources. Outdoor applications including street lighting and stadium lighting utilize very high luminance sources like HID in order to optically control the light to achieve a complex illuminance pattern on the roadway or stadium grounds while maintaining a manageably small luminaire size. Specialty lighting applications like vehicle forward lighting and projection display aim to achieve long illuminance throw, precise beam shaping, and spatial beam modulation. Specialty applications have historically applied HID technology to a great extent. LEDs have been adopted by all of these applications to some degree, and offer their well known benefits of small form factor, reliability and luminous efficacy, but are not able to be utilized in high luminance applications.

However, after significant development time, both HID and LEDs are limited from the standpoint of luminance. Development of Xenon HID light sources for automotive and entertainment lighting applications have reached luminance values of 1.5×10^8 cd/m^2 [1] or for reference approximately 1000 lm from an arc size of a couple of millimeters in diameter, although the overall size of HID lighting systems is much larger. Despite their luminous efficacy, LEDs offer luminance somewhat less than the HID example above, because efficiency droop with increasing drive power also presents a fundamental challenge for LEDs to achieve higher luminance. As a new solid state high luminance light source, laser light technology has now demonstrated luminance higher than 1.0×10^9 cd/m^2 or more than six times the highest HID.

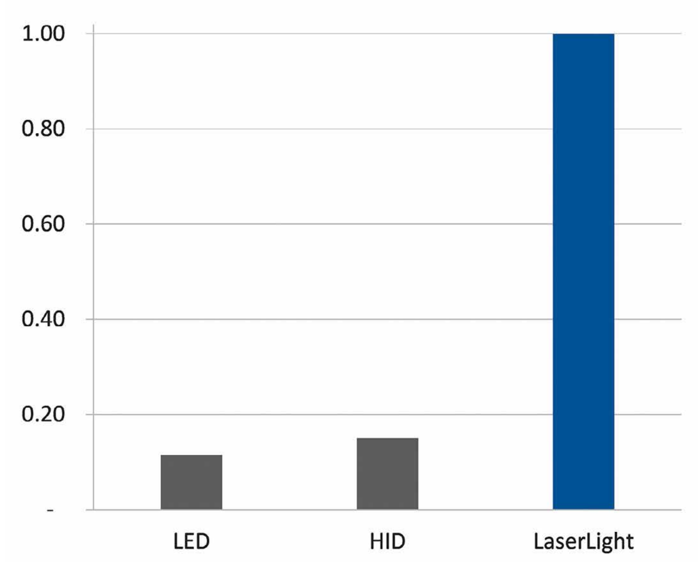

Figure 2: Relative luminance from source

Figure 3: Laser diode chip on sub-mount, wire bonded in TO package with emitting stripe visible

Fundamentals of Laser Light Technology

By fabricating a blue laser diode from semi-polar orientation Gallium Nitride (GaN), blue laser light is produced at higher levels of power due to the high gain in the device. As importantly, laser diodes show minimal droop characteristics, meaning that, for the first time, high power lasers with very small scale are being implemented in specialty lighting applications. Unlike a blue LED that emits a few watts of diffuse optical energy per square millimeter, the watts of light produced from the laser diode emanate from a light emitting area only microns in width, and can therefore illuminate a tiny spot that is hundreds of microns in diameter.

To complete the spectrum, the blue radiation is partially converted to longer wavelengths by a phosphor element. Innovations in high temperature phosphors and binding materials have enabled phosphors to convert light efficiently at the elevated power densities and temperatures that result from the laser light architecture.

Two implementations of laser light have been developed that both achieve high luminance. The first implementation is composed of a blue laser module that uses a fiber optic of arbitrary length to transport the blue light to the end where the light illuminates the phosphor element. Typical optical fiber carrying laser radiation operates at a transport

Figure 4:
Separable laser module and phosphor element linked by fiber optic

Figure 5:
SMD laser light component

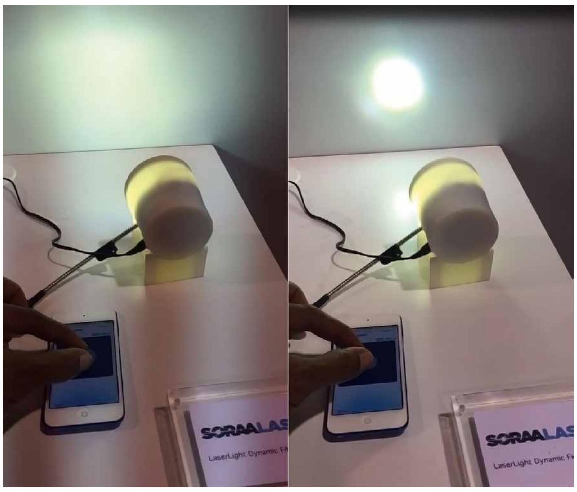

Figure 6:
Dynamic control of the beam angle with an LC lens operated by a touchpad

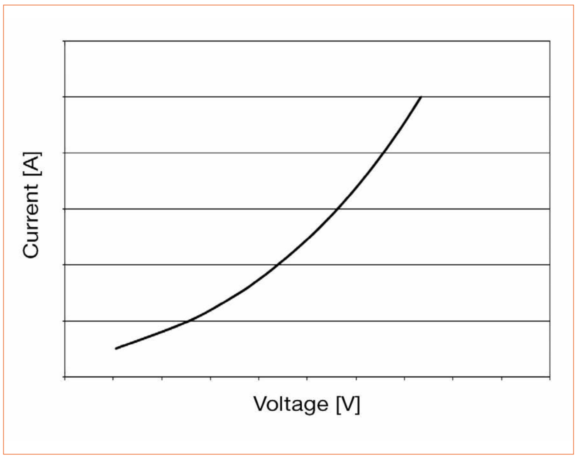

Figure 7:
Drive current vs. voltage for typical LED

efficiency of 99.8% per meter, thus losses are very small even for significant fiber lengths. With this arrangement the white light emitting element may be sealed in a location remote from the laser and its electronics which may be placed in another location that has more favorable physical and thermal characteristics.

In the second implementation, the phosphor element is placed in close proximity to the laser diodes, resulting in a fully integrated surface mount device (SMD) of 7 mm square dimensions. This configuration has been highlighted as particularly novel through its recognition by the LightFair Innovation Award judged by the IES and IALD. In contrast to other solid state light sources, the phosphor is operated as a reflecting element. This placement offers the advantage of straightforward heat sinking of the phosphor element, which is important due to the high levels of power density. Reflectance from the phosphor also enables the configuration of safeguards on the emission of blue collimated laser light. Reflected light can be blocked by beam blocks or observed by sensors both of which can ensure that blue collimated laser light is never released. In each of the two configurations, up to 500 lumens is emitted from a light emitting area only 300 microns in diameter resulting in luminance levels in excess of 1 billion cd/m^2. Efficacy of the light output also remains roughly constant as power is driven higher, due to the low efficiency droop of the lasers with increasing power.

Complementary Technologies for Laser Lighting Systems

High luminance at the laser light source provides valuable optical system advantages including narrow beam angle, sharp beam cut-off and smaller optical systems. Enabling beam angles smaller than 8 to 10 degrees from 25 to 50 mm optic diameter has been challenging with conventional light sources. Utilizing laser light sources, beam angles of 2 degrees or lower have been demonstrated with total internal reflection optics of less than 30 mm in diameter, well within convenient lighting system form factor. For existing optical systems that seek to maintain the same beam angle, the optics used may be designed to be smaller, lighter and have sharper beam geometries. Since laser light approximates a point source, the optical characteristics lend themselves particularly well to diffractive type optical elements for beam sizing and shaping. For example a light shaping diffuser element can transform the output beam of a 1 degree spotlight module to a rectangle of 1 degree by 10 degrees with efficiency higher than 92%. Moreover, liquid crystal lens technology can be added downstream from laser light modules in order to electronically control and dynamically change the beam angle and/or shape [2].

The electrical and thermal infrastructure required for laser light implementations closely resembles those already established for solid state lighting. Laser light is a current driven system with very flat voltage characteristics, thus the electronic drivers required must be capable of controlling amperage with high accuracy and stability while disallowing voltage runaway and spikes. Like other solid state illumination devices, the light output of laser light attenuates with increasing temperature and so, heatsinks are required to efficiently transport several watts of thermal energy away from each device.

The figures on the left illustrate the current vs. voltage characteristics for LED and laser light. Where LEDs exhibit gradually increasing current with voltage, lasers show a more pronounced threshold voltage/ current behavior. The sharper transition to linear electrical behavior presents a couple of considerations for electronic driver circuit design and operation. For applications where dimming is a required feature, pulse width modulation (PWM) dimming is recommended for the laser.

This is so that the drive characteristics of the device remain in the highly stable region of the curve near the rating of the device. Operating the laser at very low current levels will not offer optimal control. Secondly, the increase in current after the threshold voltage, is very steep and rapid. This slope further encourages the implementation of current control and limitation in the circuit. Current stabilized driver circuits will enhance the precision of light output control. Limiters in the current driver will prevent overdrive conditions, spikes and transients that can adversely affect the lasers reliability

Solutions in Lighting

Vehicles have been introduced with laser light for the high beam extender function and have achieved several times the throw distance previously achieved. With laser light, illuminance sufficient for visibility is thrown out to as high as 1000 meters distance. Driving safety is increased as greater braking distances at nighttime are enabled at high speeds.

Projection display applications implementing laser light are well established where laser light is modulated spatially with very high resolution, usually with a micro mirror array. The first implementations of a laser and a spinning phosphor wheel as a lighting system for projectors date from 2010. As this architecture has further developed, it is becoming more solid state and no longer using a rotating wheel, thus transitioning to more applications where very highly intelligent lighting control is desirable.

From the standpoint of creating a matrix field of controllable light, for example, LEDs have demonstrated efficacy at a relatively coarse level in automotive lighting applications. For example, these applications help to reduce glare for other drivers by using sensors and selectively dimming part of the projected light field. With an approximate point source like laser light, high precision high definition refinement of spatial light

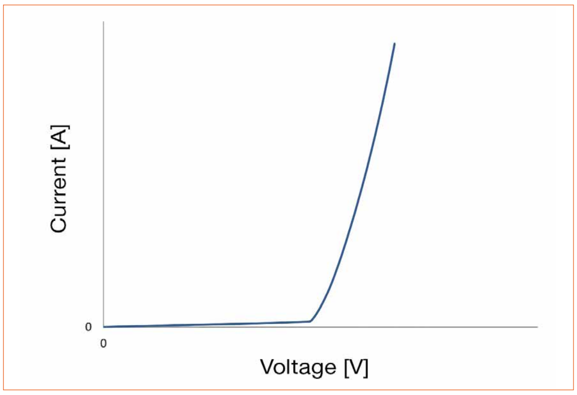

Figure 8:
Drive current vs. voltage for laser light

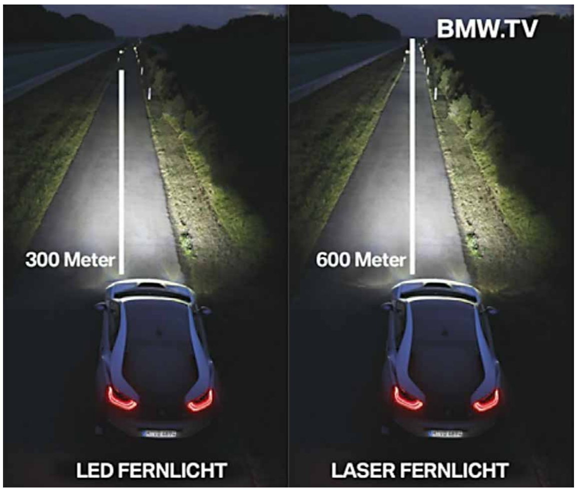

Figure 9:
Comparison between LED high beam and laser high beam (Credit: BMW)

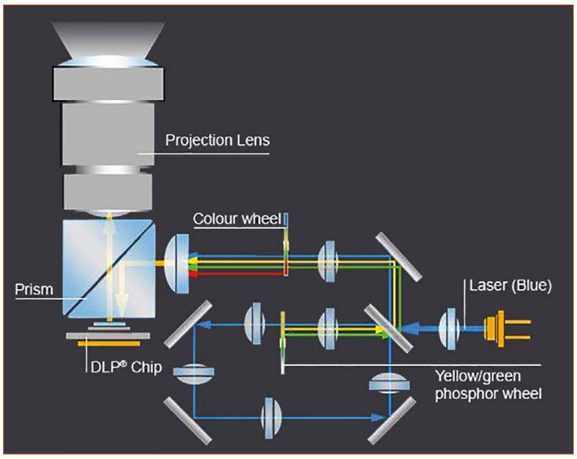

Figure 10:
Projection display design with blue laser and reflective phosphor wheel (Credit: NEC)

control is enabled, without the need for large arrays of LEDs. By combining laser light and a liquid crystal or micro mirror device in a small form factor, efficient package, automotive and specialty lighting applications may benefit.

With small form factor laser light sources like SMD emitters, architectural, entertainment and venue lighting similarly can harness a higher luminance than that available from HID in order to generate long range illumination or generate distinctive high contrast short throw illumination effects. Spots can be combined with other lensing and diffusing effects to control the beam angle and shape dynamically. Alternatively, fixed installations can use efficient micro featured diffusers to offer specially shaped beam geometries.

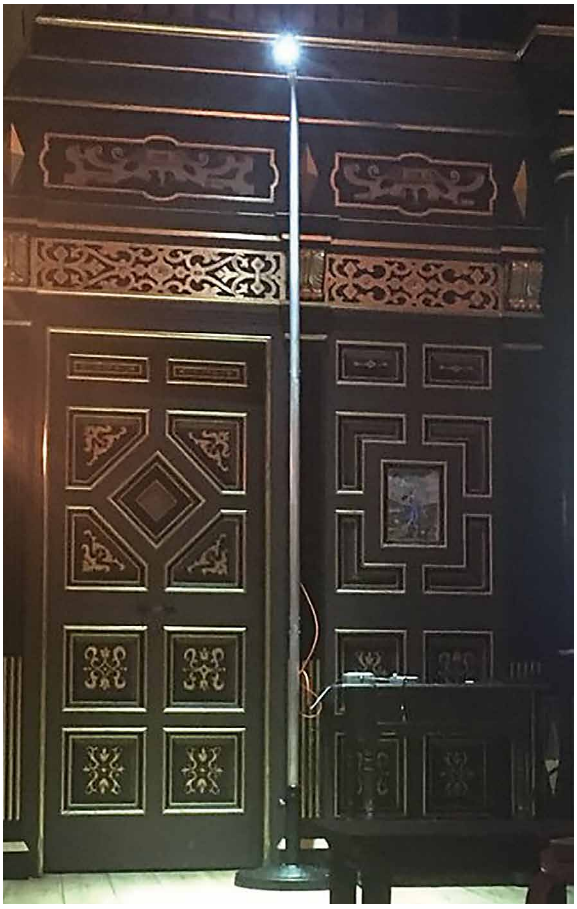

Figure 11:
Street light demo with blue laser light transported several meters by fiber to a phosphor element at top with optic (Credit: Society of Light & Lighting)

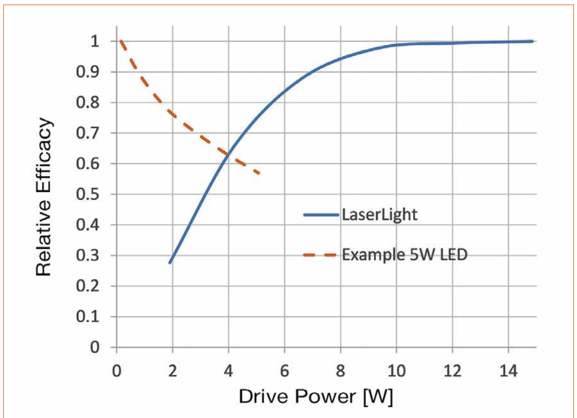

Figure 12:
Change in efficacy (lm/W) vs. power

Efficient transport of the blue laser light through a fiber optic enables designs where the white light source is purely optical and separable from the laser module and drive electronics. For example, street lights and stadium lights are an application area where this configuration offers a value proposition by reducing service needs at the light head at the top of the pole. The phosphor converting element could be permanently sealed in a lighter, smaller optical structure less subject to wind and costly service visits on a mobile lift. The laser module and electronic assemblies are positioned in the pole, base or underground.

Future Directions for Laser Light

Laser light is in the early days of its implementations in specialty lighting and performance gains are rapid. Efforts are underway to further increase luminance by driving the spot size smaller for a given lumen reference. As LEDs accomplished throughout their history, luminous efficacy will continue to improve from the approximately 40-50 lm/W level of today to 100 lm/W and beyond. Most importantly, as laser light converges with LED technology in efficacy, it will have the additional advantage of not suffering drooping efficacy with increasing power. This stability will help keep emitter populations lower and fixtures smaller as there will not be significant efficacy vs. power trade-offs for individual devices.

Development is also underway of applications that scale to higher levels of lumen output per source. Current implementations emit up to 500 lumens, and applications like venue and stadium lighting would benefit, from a system design standpoint, from individual lighting elements of several thousand lumens. Laser diodes lend themselves particularly well to being combined into a single beam, so as long as the phosphor element is properly matched, overall lumen output per source is expected to rise with new designs.

CCT and CRI for recent laser light applications are around 5700 K and 70CRI respectively, which lends laser light today to outdoor application and specialty applications. Future work in phosphors and laser diode engineering will enable more complete spectrum and allow warmer, higher CRI light for indoor applications.

Conclusions and Summary

Breakthroughs in semi-polar GaN materials have led to reliable, high power blue laser diodes. These lasers, combined with high power density phosphor components, have enabled laser light to take its place as a new platform in solid state lighting. Laser light technology delivers the highest luminance available of any light source. This enables narrower beam angles and longer throw for directional lighting applications of many types, including vehicle lighting and projection display. The success in these high intensity lighting applications, positions the technology to make great contributions to intelligent general lighting by offering higher luminance, more scalable efficacy and the capability to work with complementary technologies in a nearly ideal way to control light spatially.

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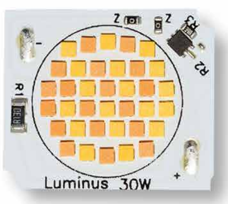

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MEDICAL ENTERTAINMENT AEROSPACE 3D PRINTING PROJECTION

Quantum Dot Based White LEDs for General Illumination

Colloidal quantum dot based white LEDs can be integrated into commercial products meeting the stringent reliability requirements for general illumination and providing LED efficiency gains of 5% to 15% over commercial phosphor based LEDs at CCT's ranging from 5000 K to 2700 K. Unlike earlier demonstrations, the QD material is applied in an on-chip configuration resulting in drop-in fit, form, and function compatibility to existing LED based luminaires and lamps. Ken T. Shimizu, Director, Novel Technologies and Devices, Research and Development, M. Böhmer, D. Estrada, S. Gangwal, S. Grabowski, H. Bechtel, E. Kang, K. J. Vampola, D. Chamberlin, O. B. Shchekin, and J. Bhardwaj from Lumileds showcase the advantages of on-chip QD LEDs: A commercial lamp at 3000K color temperature and 90 CRI is substituted with QD based LEDs resulting in a system level efficiency gain up to 17%, attributed to the reduced blue LED droop from the lower drive current and the lower heat sink temperature when compared to the standard phosphor based LED lamp output.

Colloidal quantum dots (QDs) showcase the unique feature set of a tunable band gap that can span the entire visible spectrum with nm resolution by modifying the particle size and a narrow FWHM owing to the direct transition from the band gap edge. Moreover, they exhibit fast radiative excited state lifetime and high quantum efficiency approaching unity in solution [1-4].

The recent commercial success of Samsung QD based LED TV products in high gamut ultra-high definition (UHD) televisions [5] has brought mainstream familiarity to this quantum mechanical phenomenon of a "particle-in-a-box" to everyday reality. The benefit of a narrow FWHM red and green QDs allows for more saturated colors and efficient transmission through the color filters. The same benefit of a tunable and narrow FWHM red QD in general illumination can have even greater impact in terms of color quality and LED efficiency. Although there are no RGB color filters in illumination products, the CRI and R9 requirements to provide high color quality also dictate that the spectrum of white light contain sufficient red photons that are less sensitive in response to the eye. The precipitous change in the photopic response represents a virtual filter where a narrow red emission is needed to maximize both the color quality and light source efficiency.

In the commercial display products, the solution processed QDs are embedded in a polymer film with oxygen barrier coatings applied to both sides. The QD film is placed remotely from the blue LED in the screen of the display and optically excited by blue LEDs in a separate light bar component. This allows the QDs to operate with blue light intensities at or below 1 W/cm^2 [6] and at temperatures below 50°C. To date, QDs have failed as a drop -in solution into the LED package because the LED operating temperature and blue flux intensities caused dramatic thermal quenching and fast photo - degradation [7-9]. Although the TV display manufacturers have modified the TV package to accommodate a QD converter layer, an on-chip phosphor application is preferred over remote phosphor configurations as it provides the lowest cost and lowest complexity solution for LED use, especially in cost competitive lighting applications.

We report on the on-chip application of QDs where the QD temperature exceeds 100°C and the blue flux intensity reaches 20 W/cm^2 in mid-power LED packages that demonstrate the necessary reliability requirements for commercial use and provide double digit performance improvements. The red QDs offer the greatest benefit when producing high CRI light to bring LED lamps closer to the high color quality of incandescent light sources [10]. To illustrate this effect, 90 CRI LEDs comprising of a red QD based LEDs, red nitride based phosphor LEDs, and a hybrid LED module mixing a red AlInGaP LED and a phosphor converted off-white LED are compared for their efficiency performance.

Experimental

For all experiments described in this paper, engineering builds of Luxeon 3535L HE Plus LEDs were used to validate the performance and reliability. Figure 1a shows a photo of this industry standard mid-power LED and Figure 1b shows the schematic top and side view where two 0.5 mm² LED chips are attached and wire bonded in parallel to a molded lead frame package. The package dimensions are 3.5x3.5x0.8 mm, the emitting surface diameter is 3 mm and the internal volume for the phosphor slurry is approx. 3 µL [11]. Red (625 nm) QDs in solvent-free, dry powder form with ~36 nm FWHM at 25°C (40 nm at 100°C) were received from Pacific Light Technologies. The QD, phosphor, and silicone mixture was dispensed into the LED package and cured for 4 hours at 150°C in an oven. The LEDs were solder attached following JEDEC J -STD -020D reflow procedures using SAC (tin-silver-copper) solder to a starboard for measuring light output and stress testing. Red nitride phosphor based LEDs for the same CCT's and CRI's as the QD based LEDs were fabricated in a similar fashion for direct comparison of performance and reliability.

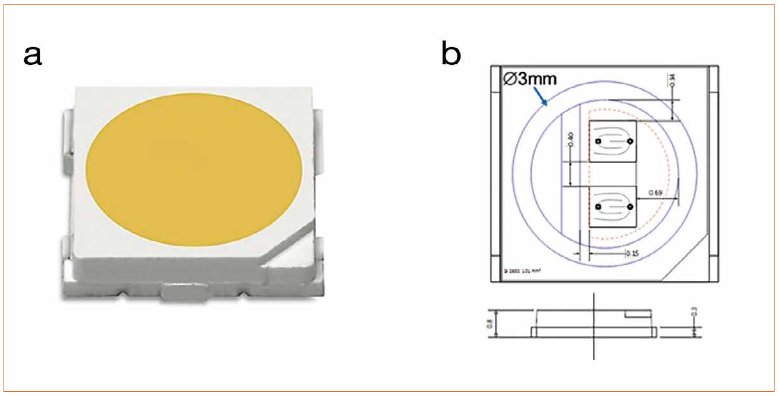


Figure 1: Luxeon 3535L HE Plus lead frame LED package was used for integrating and testing QDs in silicone resins

Table 1: Simulated FWHM dependence for LE at 3000 K and 90 CRI. Each color curve represents a fixed red emission FWHM

A		Red peak FWHM (nm)			
		30	50	70	90
Green peak FWHM (nm)	30			110%	105%
	50	117%	114%	109%	104%
	70	118%	113%	107%	102%
	90	116%	111%	106%	101%
	110	113%	109%	105%	100%

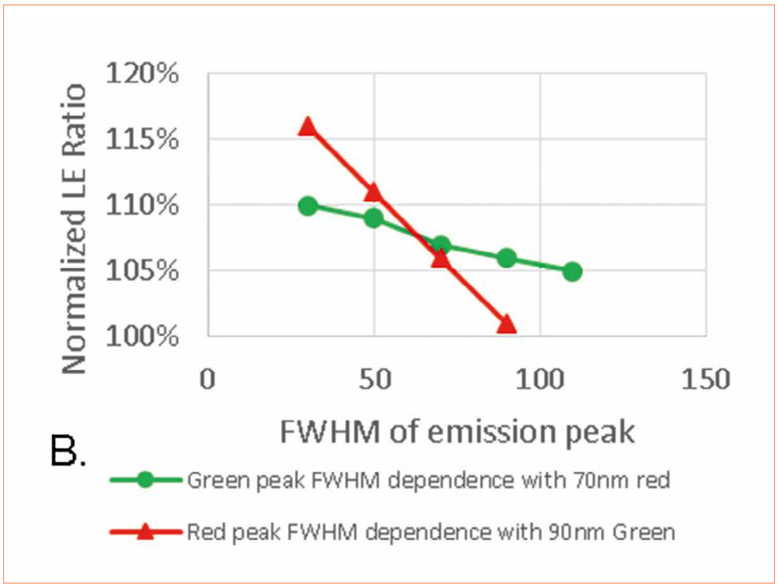


Figure 2: Plot of green and red FWHM dependence at a fixed 70 nm red FWHM and 90 nm Green FWHM, respectively

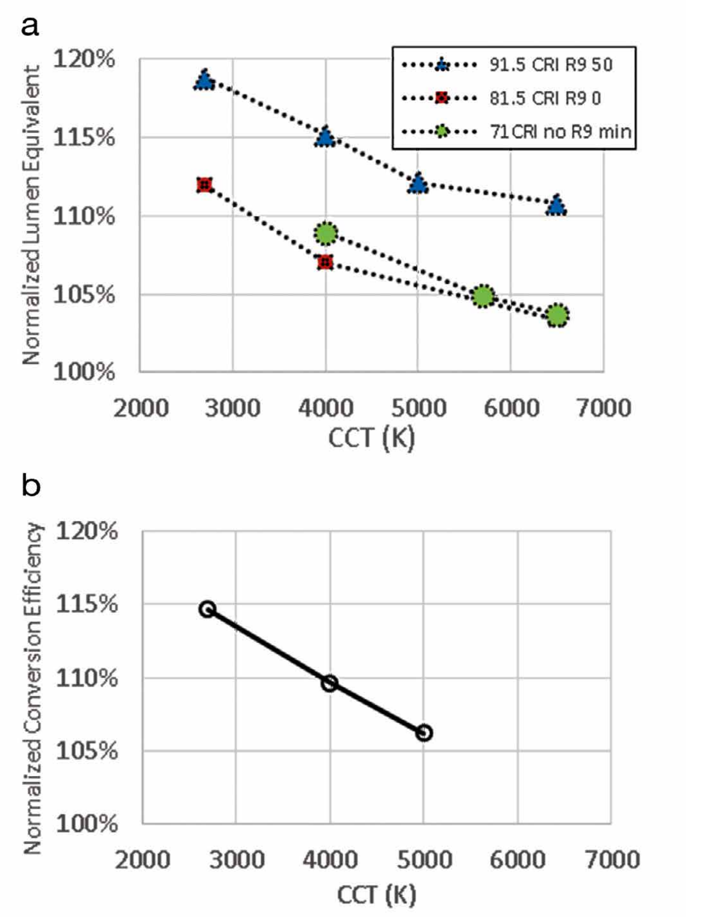
Results and Discussions

Modeling

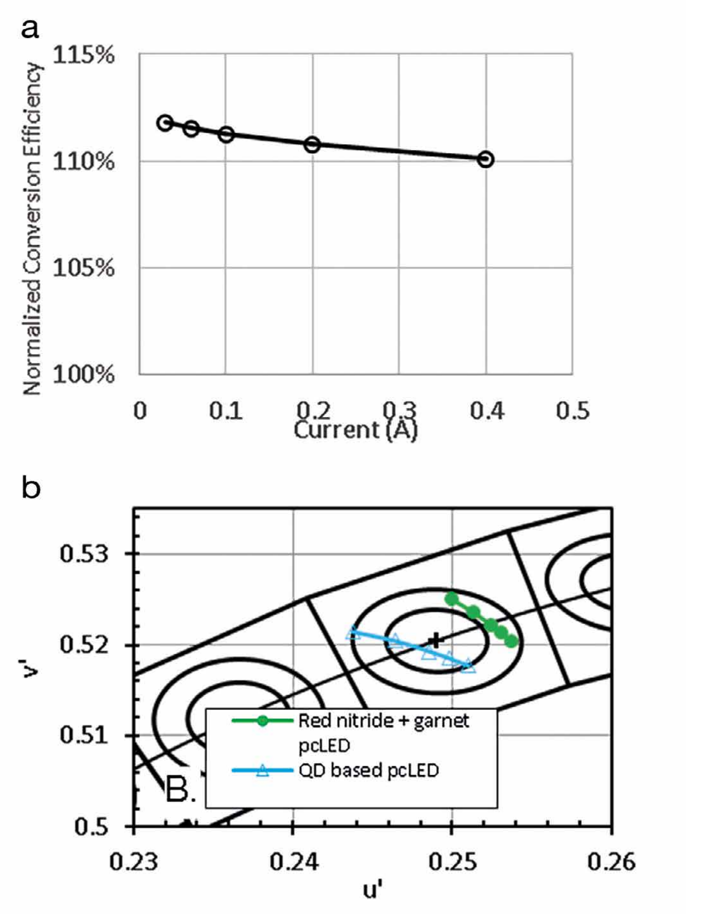
Table 1 shows the expected relationship comparing the impact of the peak Full-Width-Half-Maximum (FWHM) for red and green emitters to the lumen equivalent (LE) or lumen efficacy of radiation (LER) of white LED spectra. For simplicity, the data is normalized to the corner case of 110 nm green and 90 nm red.

The optimal LE while still achieving 3000 K CCT on the Planckian and CRI and R9 greater than 90 and 50, respectively is dramatically influenced by both the FWHM and the peak wavelength value. The blue LED peak wavelength was fixed at 450 nm with a constant FWHM of 16 nm. Figure 2, clearly illustrates the stronger FWHM dependence of the red peak on LE compared to green peak FWHM. In this example, the reduction of red FWHM from 90 to 30 nm improves LE by 15% at 90 nm of green FWHM whereas the same 60 nm reduction in the green from 110 to 50 nm improves LE by only 5% for a 70nm red FHWM value. The 30 nm green with 30 or 50 nm red FWHM were not calculated as there are no solutions to meet the required CCT and CRI for a single red and green Gaussian emission mixture.

Even though the LE increases significantly as the red FWHM becomes narrower, the sensitivity of this maximum performance to the peak wavelength also increases. For the QD based LED case (40 nm FWHM red QD peak and 110 nm FWHM green YAG peak), the LE is reduced by ~1% for each nm of wavelength red shifted from the optimal position. QDs offer the advantage of sub-nm resolution in customizing the peak emission wavelength during the QD synthesis process but also requires careful



Figures 3a&b: Modeling results showcasing LE performance expectations based on a 40 nm FWHM red QD compared to red nitride based phosphor converted LED (pcLED) (a). Experimentally measured QD based LED CE normalized to a commercial red nitride based pcLED at different CCT values (b)



Figures 4a&b: Measured CE performance vs drive current (a) and color point shift comparison (b) between red nitride phosphor and QD based LED at 3000 K, driven in DC mode and 85°C heatsink temperature

management of the peak wavelength as a function of the temperature which can shift ~1 nm per 10°C.

Figure 3a repeats the modeling over the range of warm (2700 K) to cool (6500 K) white CCTs at 70, 80 and 90 CRI values and compares the predicted maximum LE for a 40nm red FWHM and 110nm Green FWHM to measured LE performance of commercial LED phosphors. This shows that the theoretical LE gains are highest for 90 CRI due to the demanding spectral matching to the blackbody source. At 80 and 70 CRI the LE gains over conventional LEDs are reduced but still meaningful even up to 6500 K at CRI 70 or 80. The increasing LE gains for lower CCT values makes intuitive sense since there is a greater portion of red photons that make up the warm white light spectrum.

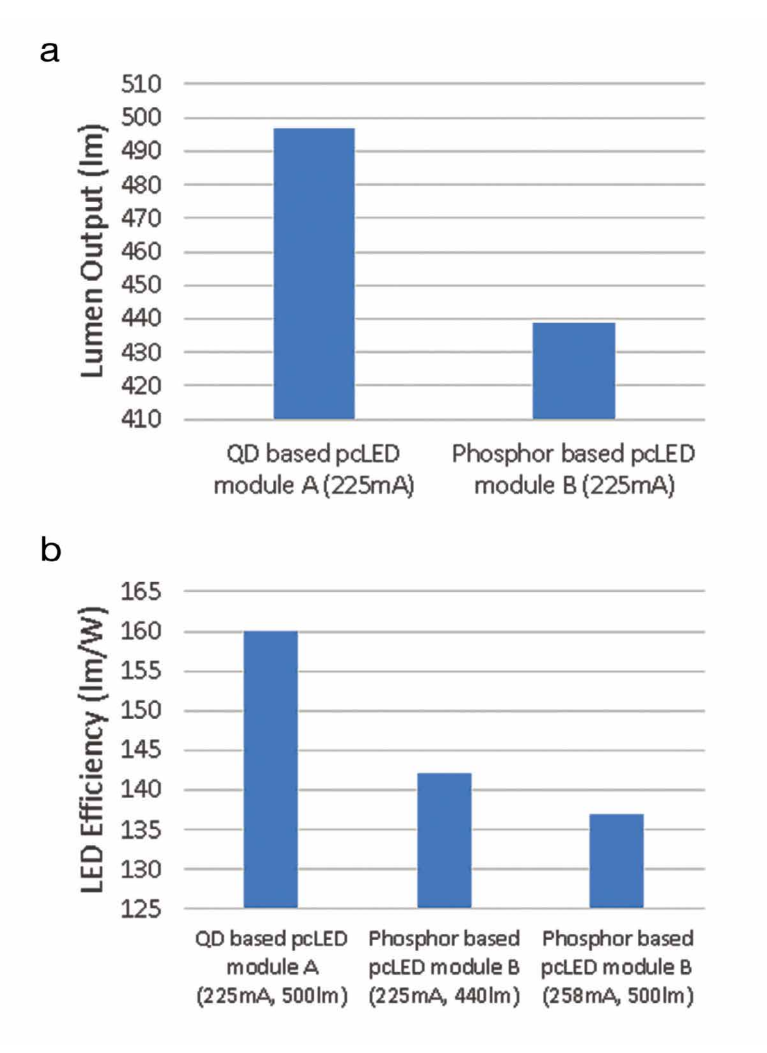
LED efficiency

In figure 3b, we show experimental data of QD based Luxeon 3535L HE Plus white LEDs at 90 CRI and various CCT's at a heat sink temperature of 60°C driven at 65 mA [12] typical for a downlight application. The QD based LED shows significant conversion efficiency (CE) improvement over the commercial red nitride based phosphor converted LED (pcLED). The CE is defined as the product of the package efficiency, lumen equivalent, the quantum efficiency of down conversion, and the Stokes shift efficiency at the longer wavelengths. The CE gains are highest at 2700 K approaching 15% gains and still above 6% at 5000 K. In comparing the LE gains of figure 3a and the CE gains of figure 3b, the CE gain is about 5% lower than the theoretical maximum LE gains calculated from the model. This difference can be attributed to a combination of QE and optical scattering differences between the QD and the red nitride phosphor and the non-optimization of the QD peak wavelength for each CCT, CRI and operating temperature.

In figure 4a, the CE performance of a 3000 K, 90 CRI QD based LED over a conventional pcLED are measured to higher drive currents and at 85°C heat sink temperature that would represent operating conditions for a retrofit light bulb. The comparison between the QD and the red nitride based LED shows 10~12 % gain at drive currents ranging from 30 to 400 mA. The QD based LED color shift over this range, shown in figure 4b, is u' = -7 pts and v' = +4 pts in CIE 1976 color space which is comparable to the red nitride phosphor based LED. The slightly larger color shift for the QD based LED is due to more reversible photo thermal quenching of the QDs which will be discussed in more detail later in the paper.

Figure 5 shows external testing results from LEDs in figures 4 and 6 that were assembled into a LED module. This example module contains an array of 15 LEDs on PCB with 3 strings wired in parallel. The QD and the red nitride phosphor based LEDs were matched with blue LED chips within 2.5 nm wavelength distribution so that the difference in performance can be attributed to the white light conversion only.

Care was taken to ensure that the LED modules measured similar color points, CRI and R9 values. When driven at the same current density, the QD based LED module produced a 13% luminous efficiency improvement compared to the red nitride based module, consistent with the results from Figure 3. In the case where the LEDs are compared at the same lumen output, the red nitride based LEDs need to be driven at a higher drive current to match the lumen output. The QD based LEDs then provide 17% efficiency gains over the red nitride based LED. Because of the significant current density droop effect of InGaN LEDs the changes in conversion efficiency have a nonlinear impact on the total LED module. Additionally, as the total efficiency of the module improves, the LED heatsink can be reduced in cost and size.



Figures 5a&b: External testing results of a QD based LED and a pcLED module on PCB board - lumen output (a) and efficiency (b)

Alternatives to QDs

The first commercial 60 W equivalent LED lightbulb was the Philips L-prize bulb introduced on Earth Day 2012. The combination of a red LED and an off-white garnet based pcLED allowed for high color quality and high efficiency performance. A case study was completed to compare the L-prize bulb to the QD based pcLED. To represent the now discontinued L -prize bulb with updated commercial LEDs, a red -orange, 1 mm^2 Luxeon C LED (618 nm peak WL and 15 nm FHWM at 25°C) was combined with a garnet phosphor filled Luxeon 3535L HE Plus whereby the spectral mixing was applied from separate LED measurements following the procedure and simulator from Y. Ohno [13]. Using a direct red LED eliminates the Stokes energy loss mechanism associated with phosphor conversion. However, the red and white LEDs are spatially separated therefore requiring additional mixing within the LED module using secondary optics to produce a uniform white light for the consumer

In figure 6, we plot the luminous efficacy of 16 off -white LEDs mixed with two red LED against 18 QD based LEDs. We calculate an optical mixing efficiency penalty of 13% for the hybrid LED system [14]. Both modules were driven to produce ~1000 lumen output at 3000 K and 90CRI. The hybrid direct red LED system shows higher efficiency compared to the QD based LED at 25°C even after accounting for the optical mixing penalty, but as the temperature increases to 85°C, the red LED

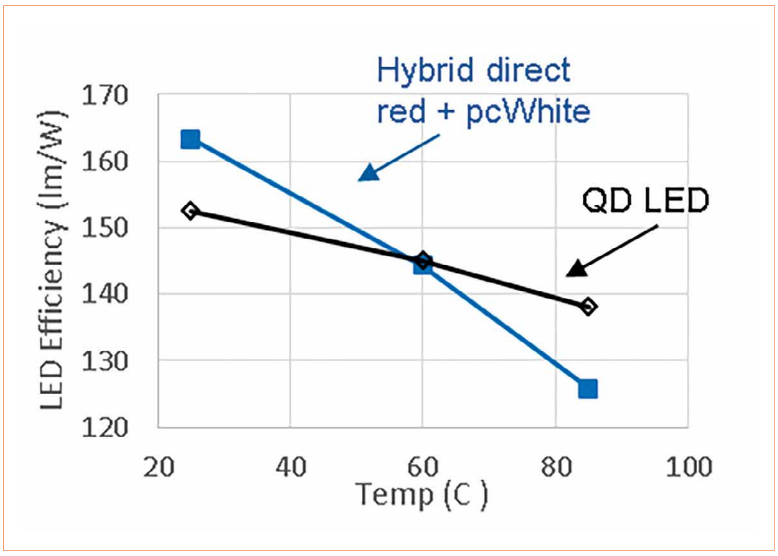
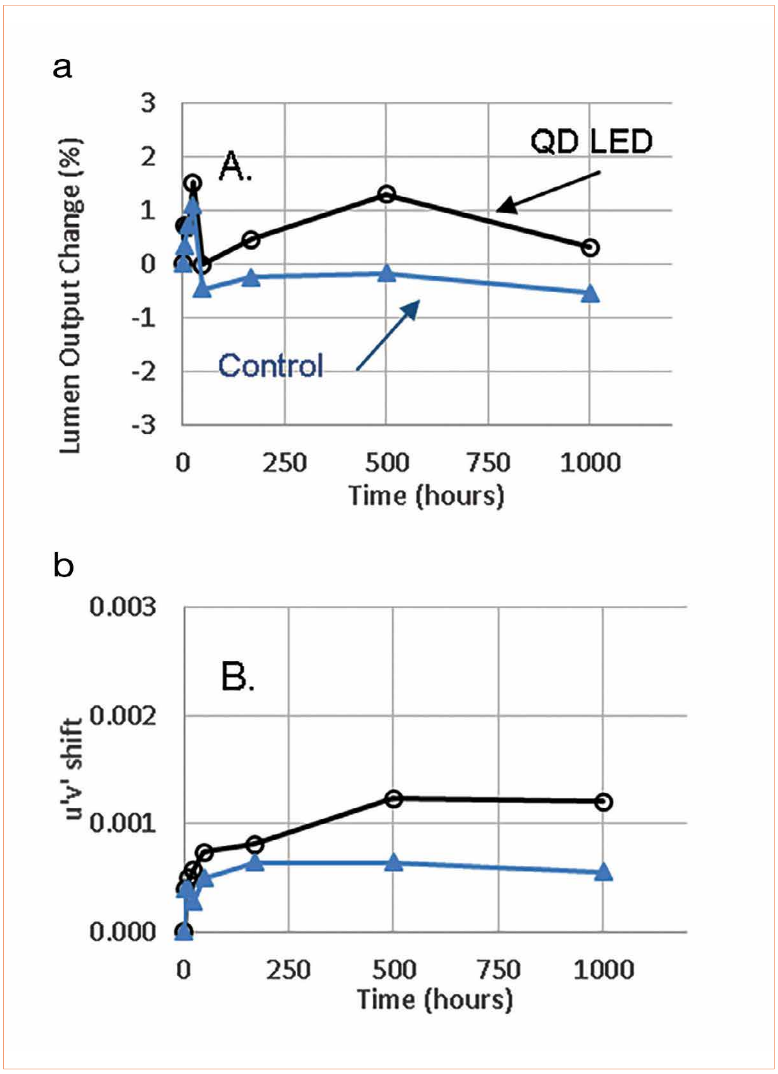


Figure 6:
LED efficiency comparison between QD based LED and Hybrid direct Red + pcWhite LED modules at different temperatures



Figures 7a&b:
Reliability of QD LEDs under 95°C and 200 mA HTOL conditions. Light output maintenance (a) and color shift (b) over 3000 hr duration

requires much higher drive current to maintain the same color point due to the thermal quenching of the AlInGaP LED. The dramatically reduced red LED performance translates into a higher overall efficiency for the QD based LED at nominal conditions. An additional advantage of the QD based LED is the simplicity and cost savings of the electronic components for the overall light fixture since the L-prize bulb requires two drivers, one for the red LEDs with temperature compensation and a second for the InGaN pumped off -white LEDs.

Reliability

In Figure 7 and 8, we show the high temperature operating life (HTOL) and high humidity or wet, high temperature operating life (WHTOL) stress testing results. Figures 7a and 7b show LED HTOL stability in terms of light output power and color shifts after operating at 95°C and driven at 200 mA for 3000 hours.

At these conditions, the QD temperature can reach over 110°C under blue flux intensities of 20 W/cm^2; however, the comparison to the red nitride phosphor based LED shows that the QD based LED can maintain light output and color stability in a similar range and within specifications. Although the long term testing is not complete at the time of preparing this manuscript, the 3000 hrs of testing show great promise that the color maintenance of *du'v'* < |0.007| marked in the dotted line should exceed 6000 hrs. Figure 8 also shows LED WHTOL stability in terms of light output power and color shifts after operating at 60°C and 90% relative humidity and driven at 65 mA for 1000 hours where the dotted line marks the maximum color shift allowed under WHTOL testing. Both the WHTOL and HTOL tests show color shifts below *du'v'* <|0.002| at 1000 and 3000 hrs respectively. This shows that the QDs are meeting the required lifetimes and the prior limitations from the surface sensitivity to oxidation and defect generation have been addressed [15, 16].

Cadmium

The QDs utilized in this paper are based on II -VI semiconductors and contain Cadmium. In the QD based LEDs, the Cd concentration ranges between ~100 ppm and ~1000 ppm based on CCT; this equates to a range between ~0.3 µg and ~3 µg of Cd per LED. QDs made with alternative non -Cd materials suffer from lower quantum efficiency and insufficient reliability. Among those systems are Si [17], InP based [18], Pb perovskite [19], $CuInS_2$ [7], and Mn-doped ZnSe QDs [20].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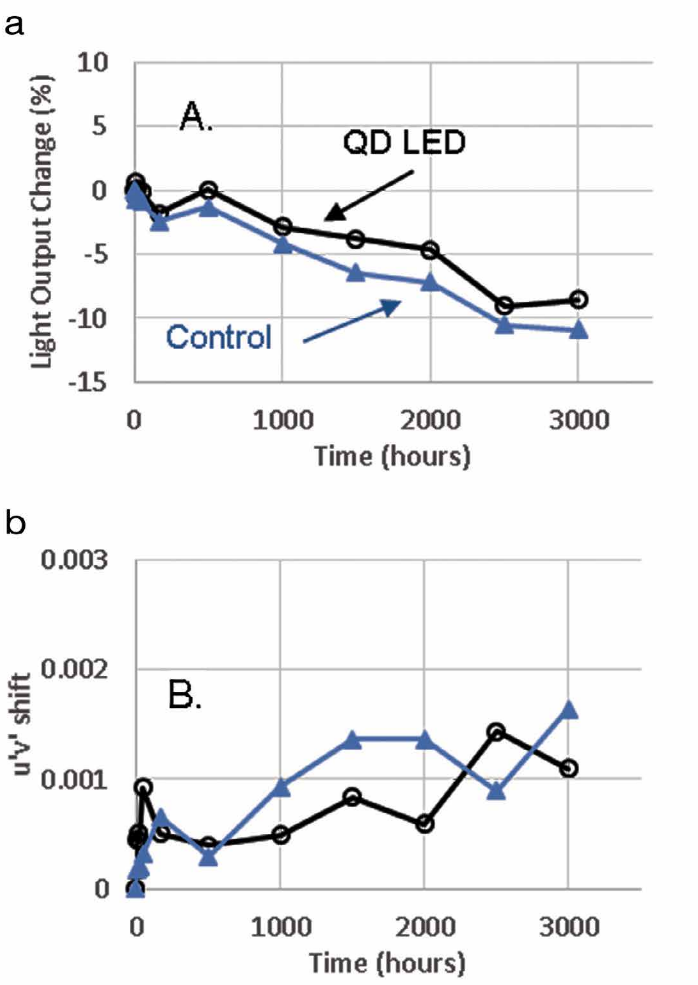
Figures 8a&b:
Reliability of QD LEDs under 60°C/ 90% RH WHTOL Stress Conditions. Light output maintenance (a) and color shift (b) over 1000 hrs duration



Other challenges with alternative non -cadmium material are limitations in achieving narrow FWHM, full tunability of the emission, or insufficient absorption at 450 nm. New materials such as Pb perovskite QDs may have similar toxicity concerns. Nonetheless, the path is clear to reduce or eliminate Cd from the QD materials in the coming years as QD material development continues at its current pace.

Conclusions

The stellar performance of the on-chip LED with Cd based QD material at high temperature, high humidity, and under high intensity light flux is a truly remarkable accomplishment in the evolving QD technology landscape. The combination of narrow FHWM and tunable peak wavelength of red QDs have resulted in 17% efficiency improvement of QD based LEDs compared to commercial red nitride based LEDs. The LED stability with 20 W/cm^2 of incident blue light and QD temperatures over 110°C have exceeded 3000 hrs and continue to show no degradation. This existence proof paves the way for improved stability of alternative QD materials and for QDs of various colors such as in display or horticultural LED applications.

Acknowledgements
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Challenges in UV Measurement

Over the past decade UV LEDs have emerged as a highly attractive alternative to conventional UV emission sources. They are cost effective and energy efficient devices in a small housing. These advantages allow new fields of applications and access to a larger group of users - even in the consumer market, e.g. water purification. Dr. Tobias Roesener, Product Manager at Instrument Systems, explains what makes accurate measurement of UV LEDs so complicated and what the crucial requirements on the measurement equipment are. In addition, he discusses calibration and stray light issues.

The development of UV LEDs and their production are technologically very challenging. UV ranges from 100-400 nm and is split into UV-A, UV-B and UV-C according to ISO-21348:

- UV-A = 315-400 nm,
- UV-B = 280-315 nm,
- UV C = 100-280 nm

However, vacuum UV from 100-200 nm is strongly absorbed by atmospheric oxygen. Particularly the UV-B and UV-C spectral ranges are very demanding. This challenge becomes apparent with the decreasing optical output power with decreasing emission wavelength (Figure 1). Therefore, the requirements for the corresponding optical measurement equipment with respect to sensitivity and accuracy are very high. Furthermore, challenges in metrology of UV radiation increases with deceasing wavelength.

The article at hand presents main challenges in the measurement of UV radiation in the context of UV LEDs. The focus is on the comparison of integrating spheres (ISP) with barium sulfate ($BaSO_4$) reflective coating (typically used for VIS and IR applications) and polytetrafluoroethylene (PTFE) reflective material for the measurement of radiant power in the spectral range between 200 and 400 nm.

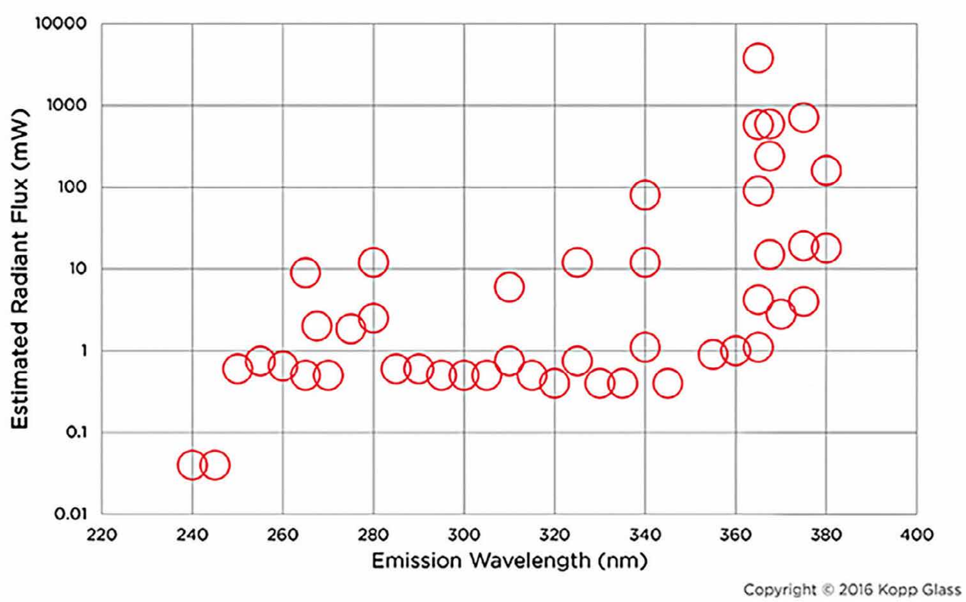

Figure 1:
Optical output power of UV LEDs decreases with decreasing wavelength [1]

Throughput

Low optical output power in the sub milliwatts regime for UV-B and UV-C spectral range requires very sensitive measurement equipment. Apart from a very sensitive spectroradiometer, an ISP with high throughput facilitates these measurements. Typically, the diffuse reflectivity of the inner surface of an ISP is chosen to be between 94% and 96%. This is a trade-off between very high throughput and measurement accuracy, on the one hand and low susceptibility to aging due to reflectivity changes on the other hand. High reflectivity allows very high throughput but even small changes result in a high change in throughput - and the other way round.

Figure 2 shows the typical reflectivity of $BaSO_4$ and PTFE between 200 and 400 nm. $BaSO_4$ has sufficient reflectivity down to approximately 300 nm. Below 300 nm its reflectivity starts dropping significantly and below 250 nm the reflectivity is insufficient for sensitive optical measurements. PTFE, on the other hand, shows reflectivity well above 94% for the entire UV spectral range.

The relative throughput of two ISPs made with $BaSO_4$ and PTFE is depicted in figure 3. The curve characteristic corresponds to the above-mentioned reflectivity properties. The throughput of the PTFE ISP is approximately 3 times larger than that of the $BaSO_4$ ISP for UV-A and -B. For UV-C the $BaSO_4$ reflectivity drops and the relative throughput increases drastically up to a factor of over 10 in favor of PTFE.

These results show that $BaSO_4$ - from a perspective of throughput - is only sufficient for UV-A, and possibly for UV-B. PTFE, on the other hand, is suitable for the characterization of UV LEDs down to 200 nm.

Fluorescence

Organic molecules from dust, exhaust gases, oil, residuals from production processes, etc. typically cause undesirable fluorescence in $BaSO_4$ and PTFE ISPs. Short wavelength radiation is absorbed and (partially) converted to fluorescence radiation at higher wavelengths.

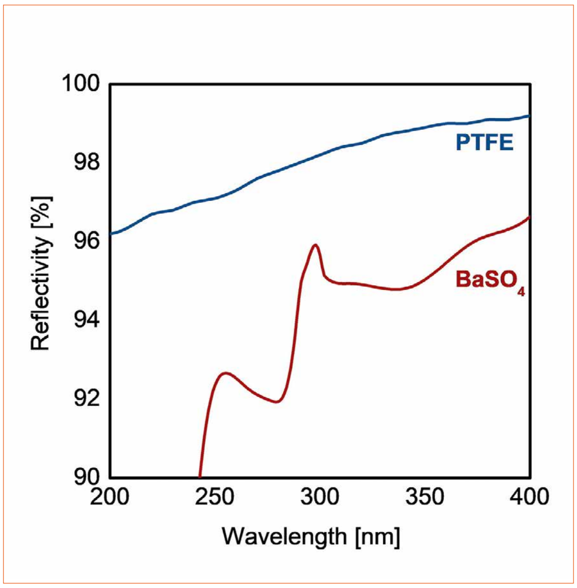

Figure 2 (left): Typical reflectivity of $BaSO_4$ and PTFE materials in the UV spectral range

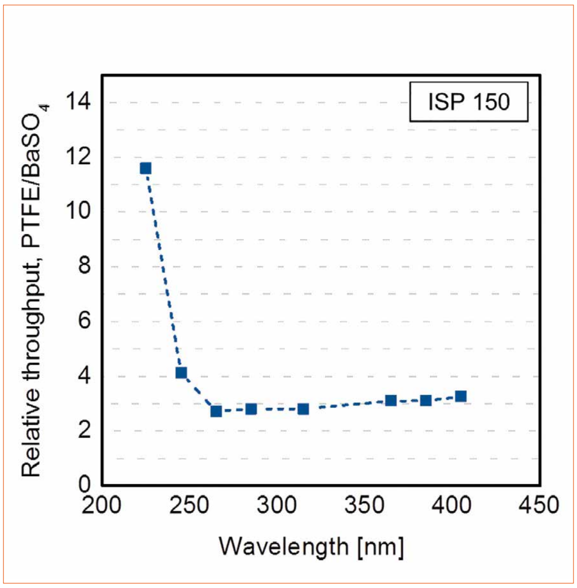

Figure 3 (right): Throughput of an ISP with PTFE reflective material relative to one with $BaSO_4$ reflective coating (both with 150 mm inner diameter)

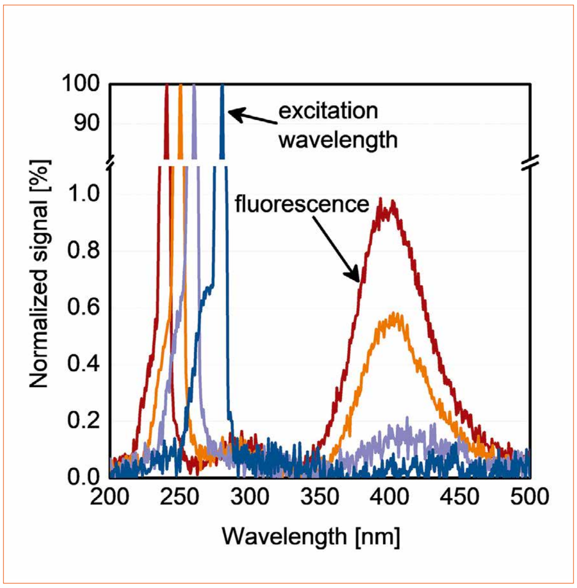

Figure 4 (left): Normalized spectra of discrete laser excitation at different wavelengths in a $BaSO_4$ ISP

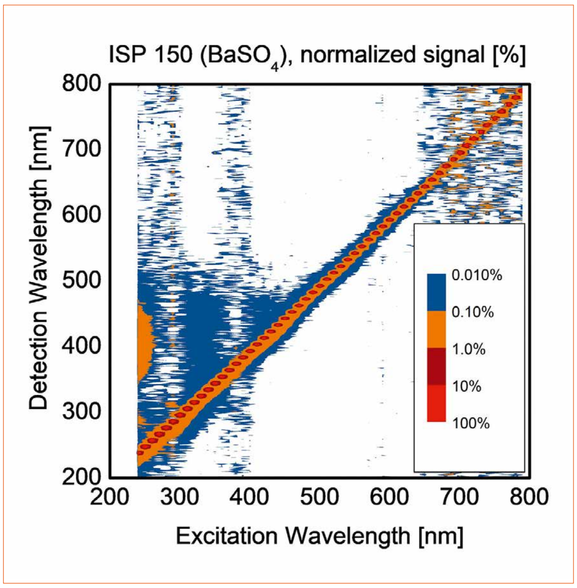

Figure 5 (right): Fluorescence matrix of a $BaSO_4$ ISP with 150 mm inner diameter

Fluorescence is therefore critical in two ways:

- During calibration the actual spectrum of a calibration lamp - typically deuterium - is “modified” by fluorescence. Radiation at a lower wavelength is absorbed causing a lower signal. Part of the absorbed energy is transferred to a higher wavelength causing an additional signal. The spectral distribution is therefore corrupted by fluorescence and will affect measurement accuracy already on the calibration level
- During the measurement, parts of the UV-LEDs spectrum will be absorbed and an additional fluorescence signal will occur at higher wavelengths (Figure 9). This effects measurement accuracy on the measurement level, e.g. for radiant power and centroid wavelength

Figure 4 shows typical fluorescence spectra measured in a $BaSO_4$ ISP. Excitation is provided by a tunable laser. The excitation at 240, 250 and 260 nm results in a broad fluorescence peak around 400 nm with up to 1%rel of the excitation signal level. Fluorescence larger than 0.1% is considered to be undesirable. For excitation above 280 nm there is no detectable fluorescence visible.

A more complete overview of fluorescence spectra than figure 4 is given in figure 5 in a “fluorescence matrix”. This color plot shows the normalized signal of fluorescence spectra excited by a tunable laser. The fluorescence of the $BaSO_4$ ISP around 400 nm for excitation wavelengths below 280 nm is clearly visible. Excitation below 240 nm does not deliver useful results due to low $BaSO_4$ reflectivity (Figure 2).

PTFE also typically shows fluorescence [2], which has different characteristics to $BaSO_4$. Figure 6 shows the fluorescence matrix of a PTFE ISP “as-is”, i.e. characterized after delivery from the supplier of the PTFE material. The characteristic fluorescence spectra of around 300 nm results from excitation wavelengths below 300 nm.

In order to efficiently suppress the harmful fluorescence, Instrument Systems developed a proprietary “preconditioning” of its PTFE ISPs. It is applied prior to calibration for high accuracy calibration and measurement. Figure 7 shows the effect of the preconditioning on the fluorescence initially excited by laser radiation at 220 nm. The fluorescence is suppressed to a signal level well-below 0.1%. The preconditioning is effective for

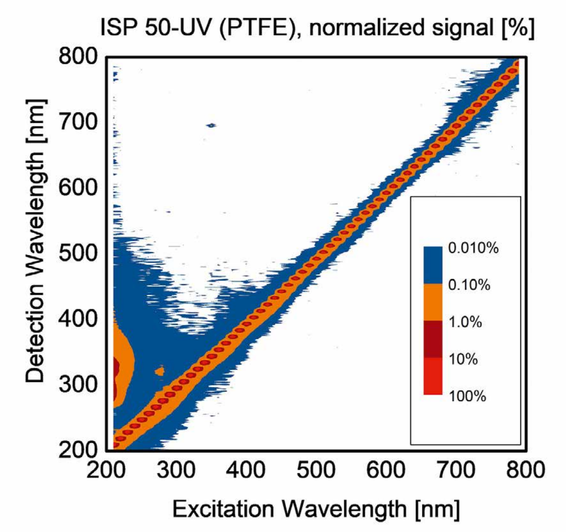

Figure 6 (left): Fluorescence matrix of a PTFE ISP “as-is” with 50 mm inner diameter

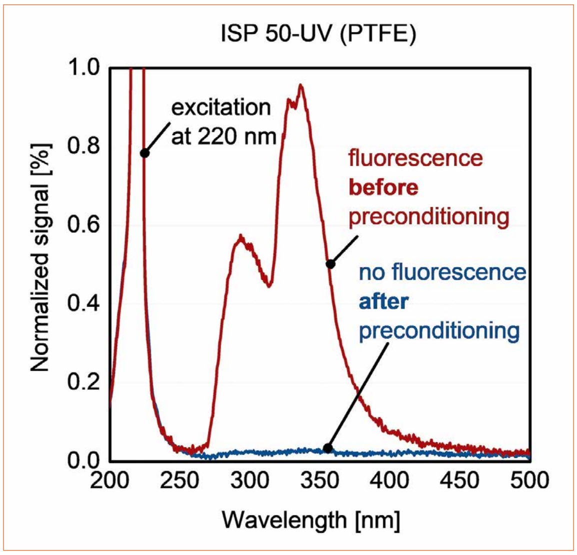

Figure 7 (right): Fluorescence spectra of a PTFE ISP with 50 mm inner diameter at 220 nm excitation wavelength. A proprietary preconditioning by Instrument Systems efficiently suppresses the fluorescence

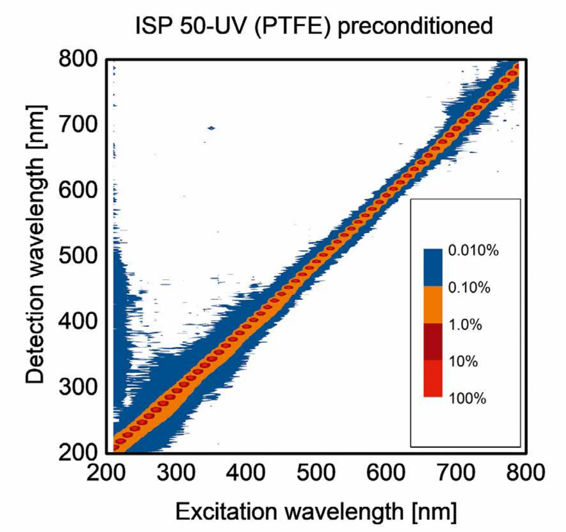

Figure 8 (left): Fluorescence matrix of the same PTFE ISP as in figure 6 after preconditioning. Fluorescence is efficiently suppressed to a level well below 0.1% for the entire UV spectral range

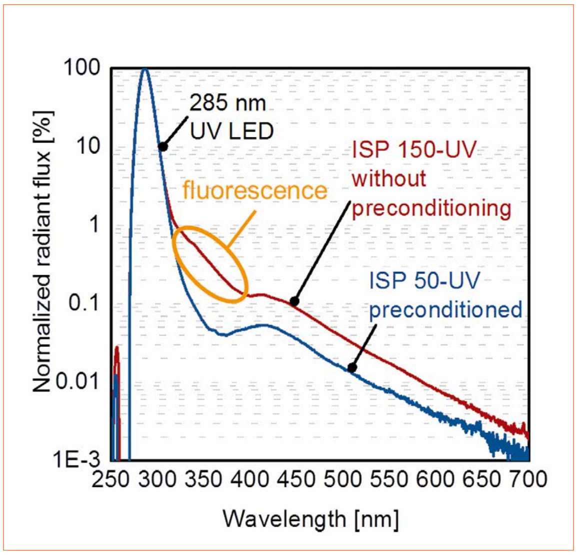

Figure 9 (right): Both measurements were acquired with calibrated equipment. The additional “blue” signal which is visible in both spectra is caused by the housing of the LED

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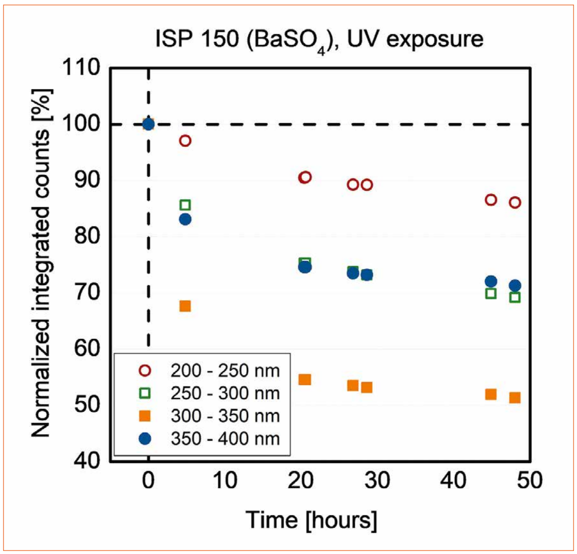


Figure 10 (left): Normalized integrated signal of a $BaSO_4$ ISP under exposure of a 30 W deuterium lamp over 48 hours. The detector signal is integrated in 50 nm intervals between 200 and 400 nm

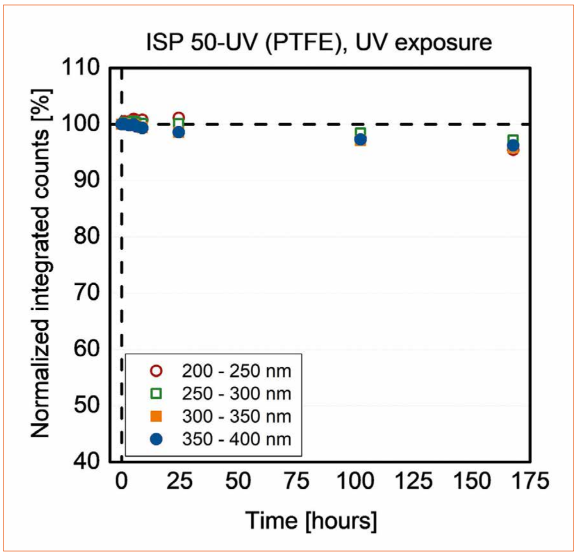


Figure 11 (right): Normalized integrated signal of a preconditioned PTFE ISP under exposure of a 30 W deuterium lamp over 160 hours. The detector signal is integrated in 50 nm intervals between 200 and 400 nm

the entire UV spectral range that is apparent from the fluorescence matrix shown in figure 8.

The effect of fluorescence on the spectrum of a 285 nm UV-LED shown in figure 9, which is measured, with an “as-is” PTFE ISP. On the long wavelength slope of the peak there is an additional shoulder caused by fluorescence. This fluorescence occurs between 300 and 400 nm, which corresponds very well with the fluorescence matrix in figure 6.

When the same UV-LED is measured with a preconditioned PTFE ISP the shoulder originating from fluorescence vanishes. The additional offset between both spectra may be due to the absence of fluorescence as well: because no radiation is absorbed at the peak wavelength the absolute signal level is higher and a normalization of both spectra to 100% results in an offset. In summary, this is a clear example of how fluorescence affects an LED spectrum.

Stability

A key requirement for optical measurement is the stability of the measurement equipment in order to guarantee long-term comparability of measurement results.
For measurements, the question is how stable are the optical components to UV exposure.
For instance, transmission of optical fibers - depending on the exact material - may degrade due to solarization when exposed to UV.

An investigation of the optical stability of $BaSO_4$ and PTFE ISPs was undertaken in order to find out about their stability to UV exposure. For this purpose the optical output of a deuterium lamp was recorded over time. Figures 10 and 11 show the integrated detector signal (normalized to the detector signal at t = 0) of a $BaSO_4$ and preconditioned PTFE ISP over 48 and 160 hours, respectively. In both cases the integration was performed for four 50 nm intervals between 200 and 400 nm. A solarization of the optical fiber was ruled out in the course of the measurement with a reference setup that was not exposed to the UV radiation.

The $BaSO_4$ ISP showed a significant degradation in throughput of up to 50% in 48 hours for the entire UV spectral range (Figure 10). It is apparent from the graph that even after 24 hours, degradation is still visible and saturation may not be expected even after 48 hours.

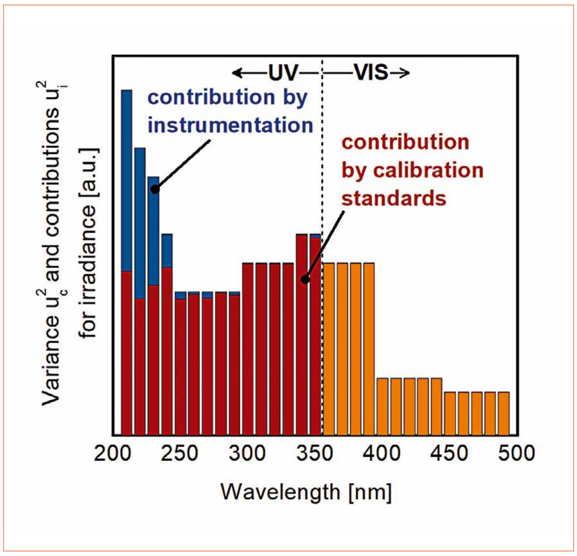
In contrast to that the preconditioned PTFE ISP shows only very little drop in the integrated signal over 160 hours - equally for the entire UV spectral range. This minor drop over such a long time, however, can be attributed to the degradation of the deuterium lamp - which is known not to be stable over such a long duration - rather than a degradation of the PTFE ISP throughput.
In summary, a preconditioned PTFE ISP is the measurement probe of choice when stability to UV exposure is vital.

Measurement Accuracy

Measurement accuracy is paramount for the reliability and comparability of optical measurements.
Every measurement has a uncertainty that originates from emission stability of the calibration source, environment, calibration methodology, instrumentation, etc. These uncertainties contribute to an uncertainty budget that has to be evaluated for each individual measurement setup. It is expressed as the combined variance u_c^2 for a certain measure and $y = f(x_1, x_2, \ldots x_N)$, e.g. radiant power and corresponds to the sum of variances of y resulting from variations of each input x_i [3]:

$$u_c^2(y) = \sum_{i=1}^{N} \left[\frac{\partial f}{\partial \partial} u(x_i) \right]^2 = \sum_{i=1}^{N} u_i^2(y) \quad \text{(EQ 1)}$$

The so-called “expanded” measurement uncertainty corresponds to a 95% confidence that a measured result is within the given confidence interval (for normal distributed quantities the expanded uncertainty is twice (k = 2) the standard uncertainty). This expanded measurement uncertainty



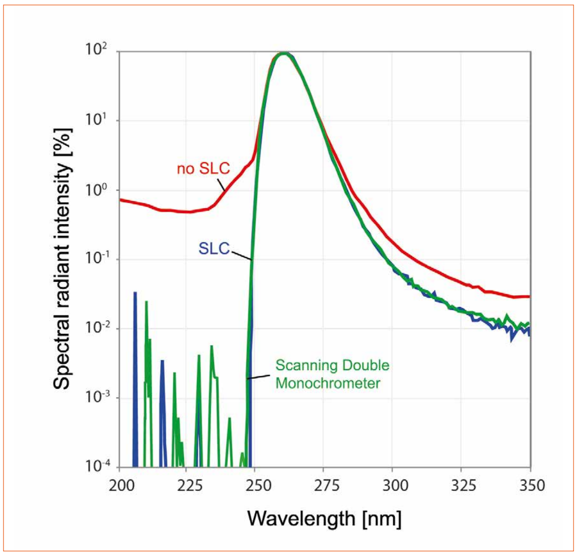


Figure 12 (left): Measurement uncertainty in terms of combined variance u_c^2 for irradiance in the VIS (orange) and UV spectral range. For UV the measurement uncertainty is split by its variance contributions u_i^2 from calibration standards and instrumentation according to formula (1)

Figure 13 (right): Effect of a state-of-the-art numerical stray light correction (SLC) on the measured spectrum of a UV-C LED [5]

particularly includes the uncertainties given by national laboratories (e.g. NIST, PTB) for their calibration of standards which are the reference standard for calibration at spectroradiometer manufacturers.

In the VIS spectral range calibration standards are available with quite low uncertainties from national laboratories. In contrast to that, for the UV spectral ranges no calibration standards are available for radiant power below 300 nm.

A workaround for LED measurements are calibration standards for spectral irradiance. These can be used to perform calibrations of spectral partial radiant power by a conversion from spectral irradiance. However, the uncertainties for UV spectral irradiance standards are comparatively large in contrast to the VIS spectral range. Figure 12 shows an example of the relative measurement uncertainty (in terms of combined variances u_c^2) for Instrument Systems calibration to spectral irradiance / spectral partial radiant power. Compared to the measurement uncertainty in the VIS above 400 nm the measurement uncertainty in the UV is 2 - 4 times larger. However, the uncertainty in the UV is dominated by the contribution of the calibration standards (red). For wavelengths below 250 nm the instrumentation of Instrument Systems (blue) contributes significantly to the measurement uncertainty.

Instrument Systems is currently working on advanced calibration procedures and an improvement of instrumentation to further reduce measurement uncertainties in the UV-C spectral range. Particularly, a high throughput and low fluorescence ISP may contribute to these improvements as well as a stray light correction of the spectroradiometer (Figure 13).

Stray Light Correction

Each pixel of an array detector is assigned to a specific spectral range. Light from another spectral range falling on that same pixel is considered stray light which compromises the measurement result because it adds additional signal to this pixel. Stray light is an intrinsic property of the spectrograph and is caused by grating defects, higher diffraction orders, reflection and scattering on surfaces, and many more. Stray light suppression in the UV spectral range is very demanding and poses a challenge even to very advanced spectrographs with high stray light suppressing design, e.g. Instrument Systems' CAS-series.

A state-of-the-art numerical stray light correction (SLC) was suggested by Yuqin Zong (NIST) [4]. This methodology was implemented at Instrument Systems for improved stray light suppression of CAS series spectroradiometer and higher accuracy measurements in the UV spectral range [5]. Figure 13 depicts the effect of the SLC. It shows the spectrum of a UV-C LED at 260 nm with and without SLC. Stray light is suppressed many orders of magnitude to a level comparable with a scanning double monochromator.

Summary

An overview on the main challenges of radiant power measurement of LEDs with ISPs in the UV spectral range was given.

The following two tables summarize the assessment of $BaSO_4$ and preconditioned PTFE ISPs with respect to throughput, fluorescence and stability to UV exposure which are three key performance indicators highly relevant for UV measurement.

In summary, PTFE ISPs are particularly suitable for radiant power measurements in the UV spectral range. Particularly, a proprietary preconditioning of PTFE by Instrument Systems ensures efficient fluorescence suppression and enables sensitive, accurate and reliable UV measurements.

Measurement accuracy for radiant power in the UV spectral range down to 200 nm is currently limited

$BaSO_4$	Throughput	Fluorescence	UV stability
350 - 400 nm	R > 94%	< 0.1%, noise	not stable to UV exposure
300 - 350 nm	R > 94%	< 0.1%, noise	
250 - 300 nm	R < 94%	> 280 nm: < 0.1% < 280 nm: > 0.1%	
200 - 250 nm	R ≪ 92%		

Table 1: **Summary assessment of key performance indicators for $BaSO_4$ ISPs**

PTFE	Throughput	Fluorescence	UV stability
350 - 400 nm	R ~ 98%	< 0.1%, noise	stable, preconditioned
300 - 350 nm	R ~ 98%	< 0.1%	
250 - 300 nm	R ~ 97%	< 0.1%, preconditioned	
200 - 250 nm	R ~ 96%	< 0.1%, preconditioned	

Table 2: **Summary assessment of key performance indicators for (preconditioned) PTFE ISPs**

by the non-availability of UV calibration standards from national laboratories. Spectral Irradiance calibration standards, which may be used for conversion to spectral partial radiant power currently, lack low measurement uncertainties comparable to VIS calibration standards. This equally affects all spectroradiometer manufacturers. However, Instrument Systems provides highly precise measurement solutions for UV with a high degree of comparability. Additional benefit for accurate UV measurement is provided by a state-of-the-art numerical stray light correction that reduces stray light by a few orders of magnitude for UV LEDs. ■

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Lighting to Achieve Optimal Appearance

Visual appearance of an object or space depends on the characteristics of the lighting applied. The objective definition of light quality often doesn't tell the whole story. Light intensity, its spectral composition and distribution in space, as well as individual preference, must be considered. Nevertheless, aiming for the absolute optimum is only recommended when private rooms are concerned. As visual appearance is key in driving consumer demand, it is important to tune the light to maximize effectiveness and visual pleasure for most consumers. Markus Reisinger, owner and CEO of the Lighting Research Studio, discusses this complex situation with examples.

Visual appearance of an object or a space depends on the characteristics of the lighting applied. Among the parameters that influence appearance are light intensity, its spectral composition and the distribution in space. If all parameters are well chosen a consumer will experience the setting as a visually orchestrated scene. If parameters need to be tuned for optimal appearance, then individual preference must be taken into account. It is likely that solutions for different people show similarities, but at the same time it is very unlikely that one setting is optimal for a group of people. This is because different personal experiences do influence expectations. Also different sensory and cognitive capabilities do impact what is perceived. Thus aiming for the absolute optimum is only to recommend when private rooms are concerned. For other spatial situations the immediate goal is to reach conditions that are acceptable for all. In an additional step, the group can aim to find conditions that are close to optimal. As already mentioned optimal appearance depends on the perceiving subject, but it also depends on the context. A person that likes one light setting in an office will characterize the same setting as boring when present in a hotel lobby. For many spaces, objects, surfaces and products, their visual appearance is key in driving consumer demand. Therefore it is important to tune the light to maximize effectiveness and visual pleasure.

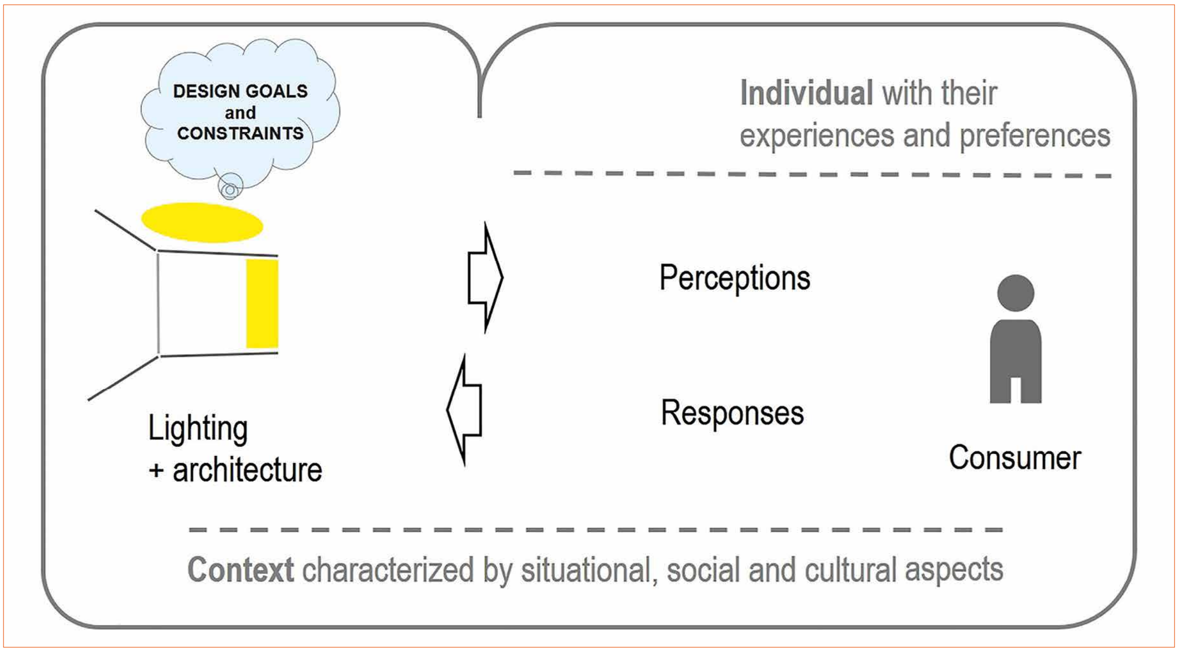

Figure 1: A basic model of consumer response to lighting

Consumer Response and Model

The behavior of consumers is a result of their intentions and how they evaluate cognitively and affectively the situation. The following scheme visualizes how lighting design can influence consumer behavior. By setting relevant goals and following them up in the design, spatial settings are produced that evoke intended pictures and behaviors in the consumer.

The model points out that individual preference and situational factors are moderating perceptual processes and responses. For example, individual preferences for colors depend a lot on a person's scope of experiences. What one person likes or dislikes will also depend on the personality and the socio-cultural context that shaped their opinions. Among the situational factors there are sequence effects, social setting, location and time specific features that impact decisions. Good lighting has a positive impact on the experience of a place. Successful lighting concepts take context specific requirements into account. Results from empirical studies are excellent opportunities to ensure that a lighting solution is adequate for given context. Research studies are often executed in idealized conditions, therefore it is important to check that settings are comparable and thus allow transfer of the results. As an example of a preference study, the results of visual appearance under warm (3000 K) and cool (4000 K) LED lighting are provided [1]. The mentioned paper additionally includes a section that shows the usage of semantic space to categorize perceptions along the axes warm-cool and hard-soft.

The results confirm that LED lighting with a correlated color temperature of 3000 K is generally preferred for reddish hues. Cooler light is generally preferred for bluish hues. Preferences for

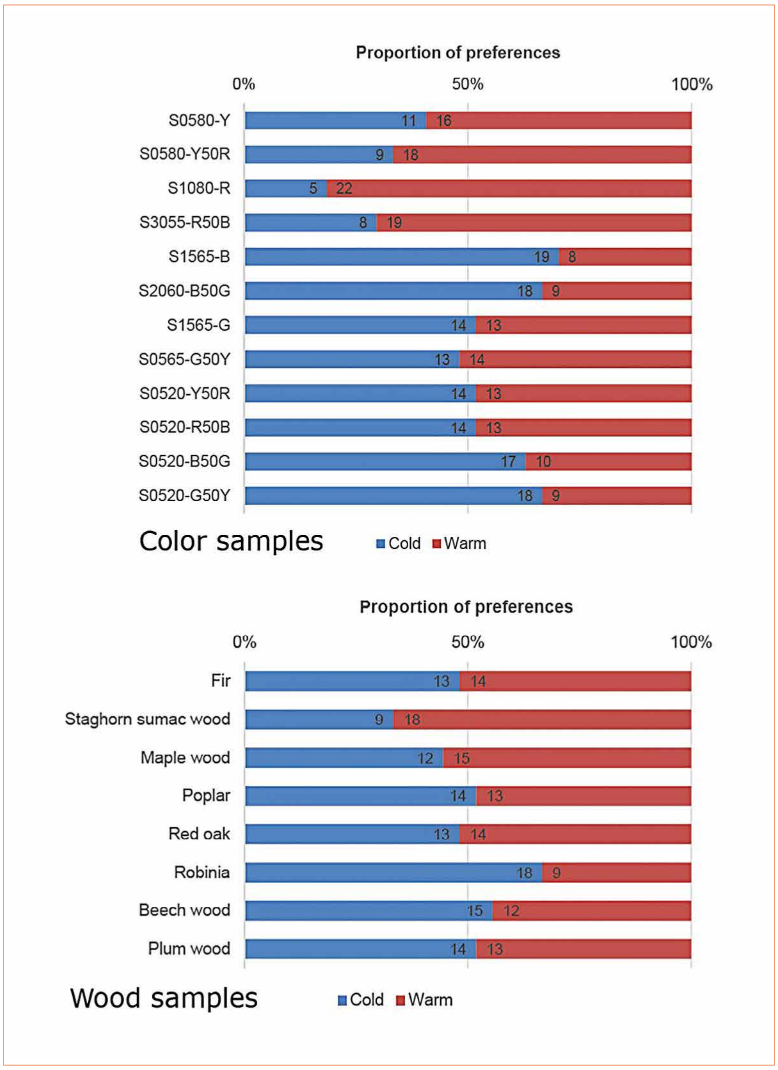

Figure 2: Preferences for appearance of color and wood samples in cool or warm light

other hues including the pastel samples were not fully conclusive. The wood samples show by tendency, that cooler light suit wood surfaces as robinia better. This cannot be explained by the spectral reflection characteristics. Therefore it can be assumed that the appearance of wood surfaces is influenced by grain, texture pattern and gloss. Focusing on the appearance of materials, one may structure specific characteristics along three modes of appearance. Green-Armytage and Caivano describe that matt, glossy, textured and metallic aspects of appearance are characteristics of the surface mode of appearance. The volume mode can vary between clear (transparent) and cloudy (translucent). In the illuminant mode light sources may appear in varying degrees of brightness with a maximum that can be described as glare [2].

It requires a deep understanding of the effects of light and constraints to master light and therewith optimize appearance. Dependent on the spatial distribution of light surfaces appear uniformly lit or not. The main direction the light comes from articulates itself in the shadowing pattern. Software packages for lighting simulation are today, the most common tools to plan the luminous environment. Rendered pictures simulate distributions of light and the appearance of objects. In the future, descriptions of the light field could become an alternative tool to predict appearance. Also, in the domain of color appearance there are more and more tools available to anticipate the impact that different spectral power distributions of light have. One example is provided by the Illuminating Engineering Society of

Table 1: Technical tools to predict appearance

Lighting dimension	Tool	Aim	Measurement
Spatial distribution	Rendering tools, Simulation software	Visualize appearance	Luminance distributions, Contrast
Spectral distribution	Color appearance models, IES TM-30-15	Quantify color shifts	SPD, ΔE

North America (IES). The technical memorandum TM-30-15 defines a method to characterize color rendering properties [3]. The role of these tools is to link measurable physical quantities to perceptual correlates. Lighting variables that influence visual appearance can be categorized according to their spatial, spectral or temporal characteristics. Technical tools that deal with the spatial and the spectral dimension are mentioned in table 1; Professional tools that cover the temporal dimension are not yet available.

Nowadays, there are an increasing number of software packages for optic simulation and lighting simulation that work with spectral data sets. Most probably not very far in the future, simulations of spatial and spectral domains will merge. Multispectral images are other examples where spectral and spatial data is collected. One bottleneck for these approaches is that there are no displays that are able to represent resulting images.

Case Examples

Shopping at the market or in the grocery store? There are certainly many reasons why you should buy groceries either at the market or in a shop. To focus on the impact of lighting, only reasons that impact visual appearance are considered. The lighting design for the grocery store was executed under the premises to achieve a natural appearance. Hence, the chosen light equipment mimics daylight and provides light with a correlated color temperature of 6000 K. The light level is within the range that is typical for shop applications. This case is meant to map challenges that are associated with achieving optimal appearance.

What the two female customers observe in the shop is indeed, in respect to color, a very natural appearance of fruit, vegetables, meat and fish. On the other hand both costumers have extensive experience from other shops and have in mind that food is often illuminated with light that corresponds to a CCT of 3500 K or 4000 K. Lighting specialists know from a study with multispectral images that an average CCT of 4500 K was preferred for all four food categories [4]. The impression of the customers is that the groceries in the shop don't look convincing enough. What they implicitly do is to link a not fully satisfying appearance to the quality of the goods and not the light condition in the shop. This behavior is typical. Only when there are very obvious indicators for failures in shop design or maintenance customers start to consider the role of lighting. For the two customers the conclusion is clear, the food in the shop does not look attractive enough so they will not buy here. A short while later the two reach the market. Temperature outdoors is comfortable; the sky has a few clouds. The light level outdoors is somewhat higher than in the shop but the appearance of fruits, vegetables, meat and fish is very similar to the appearance in the grocery store. Despite that, interpretations are quite different. Indeed everything looks natural.

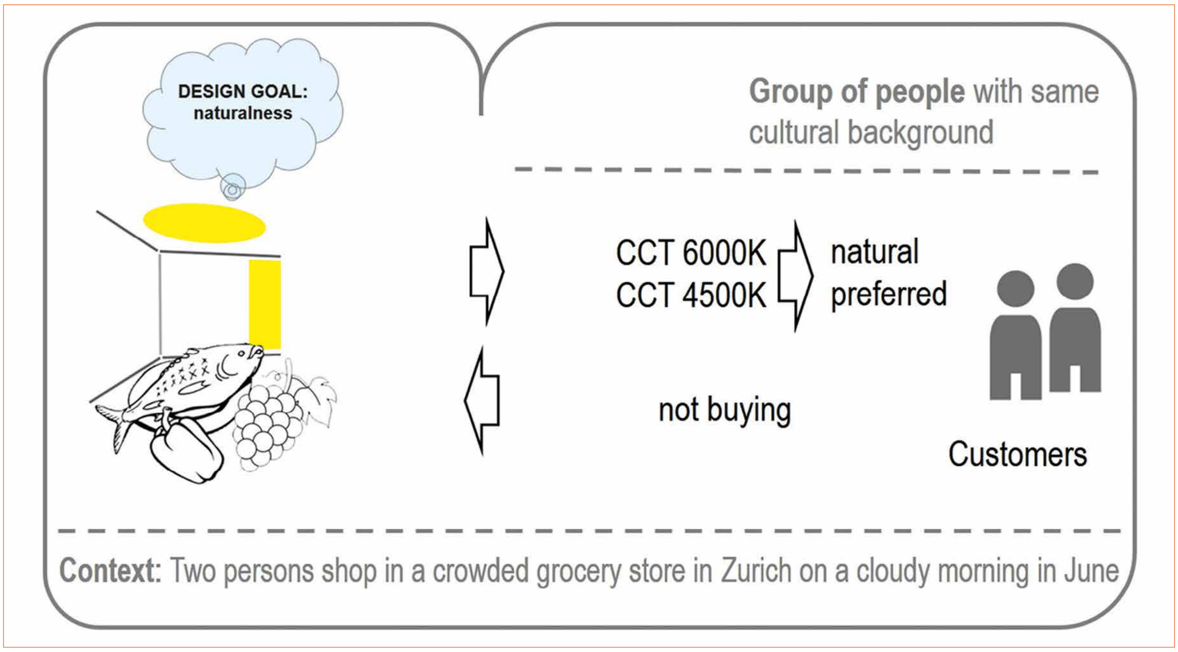

Figure 3: The grocery shopping case

As they are now outdoors, this look is also the preferred one. If color temperature is measured it would prove that it corresponds exactly to the situation inside the shop. In the end, the two customers buy their food here. Unconsciously they also check preference patterns as they look some meters ahead. One person forgot to switch off the halogen floodlight he has used in the morning. The goods shown in a mixture of electric light and daylight do appear in this situation not as natural as the other. They simply look less attractive and are less preferred by consumers at the market.

The grocery shopping case can illustrate several important perceptual aspects. A consumer's decision is strongly influenced by processes that happen unconsciously. Right at the beginning when a person starts to observe a scene, the human visual system extracts the gist of it [5]. All following perceptions are guided by this first impression. Visual and spatial references also influence what consumers expect and what finally perceive. The case demonstrates how important it is that lighting appears adequate for the given context. It is not that the color temperature per se defines what is preferred. It is the achieved fit with the temporal and spatial context. Being with two persons might also influence awareness about specific details or cause requests to align visual impressions with each other. Through an active exchange, it might occur that perceiving subjects pull aspects of color quality, contrast, and modeling or brightness distribution out of the unconscious state.

For some specific applications there is a strong interest to study visual appearance and preference. One of the fields that are well examined is materials used for car dashboards. But also in such privileged context it is a challenge to understand interactions between color, gloss and texture. Even more complex is the situation when metallic and translucent materials are included. That interaction effects can have a dominant presence and can be easily demonstrated with a material sample that has a directional tread. When the material thread is aligned with the light direction, then the resulting visual pattern is very calm. If lighting direction and thread direction are perpendicular, than the visual pattern is so different to the first case, that the observers do not believe that they are looking at the same material [6].

Summary and Conclusions

Throughout the last few years, enormous progress has been made to differentiate responses to visual stimuli. Today much is known about affective responses, interest, surprise and liking. Also, considerable advances were made in understanding symbolic meaning, semantic interpretation and aesthetic impressions. Models about aesthetic experience suggest that cognitive processing of context and content take place parallel to each other in independent channels [7]. At the same time all approaches to study visual perceptions without considerations of other senses have limits. The framework of total appearance might point out a future direction. It was developed for application in the food sector and integrated nonvisual aspects of appearance such as smell, taste (flavor) and also texture as felt in the mouth, in addition to visual texture [8]. Application domains as shops and museums are recognized for their high demands in respect to lighting quality. Among all solutions that are good enough to be accepted, there are some that are more preferred than others. What science cannot provide are recipes for optimal lighting. But from studies, traits can be extracted that guide design. ■

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Trends in Horticulture Lighting

Cree has been a leader in general lighting applications for over 20 years and has customers ranging from restaurant chains to global government agencies. Paul Scheidt began his career in Cree in 2005, working on the development of their lighting applications. During this time, he has seen an increase in the horticulture lighting application. LED professional spoke to Paul Scheidt about horticulture lighting and what he thinks is behind this recent trend. He also shares his views of what he thinks the future holds for both Cree and horticulture lighting applications.

LED professional: When we recently met in Philadelphia at LFI you sparked our imaginations when we spoke about horticultural lighting. When did Cree move into this lighting application field, and how did you become interested in it?

Paul Scheidt: I have been with Cree for 12 years and I have been focused on lighting applications for most of this time. Cree is a world leader in general lighting applications but we had seen, from our existing customer base, specifically in the United States, a growing interest in our horticultural lighting applications. This has mainly happened over the last two years. Our customers that were using horticultural lighting started to grow in terms of their production size. It went from our clients having very small accounts, with the niche players, to much larger contracts as the adoption of their products was growing.

The industry as a whole at this point started to pay attention to the application. The process was, if you'll excuse the pun, very organic. We saw our customers focusing on the application and our customers growing in size. Through that, we then started to learn more about the application; specifically about what kinds of LEDs people are looking for and in what direction the market is headed.

LED professional: It's fascinating how these trend cycles begin; can you tell us what changed in order for this shift in horticultural lighting to happen? And why now?

Paul Scheidt: The factors driving it depend on where you are. From the US prospective, especially in California, a lot of drivers have come from the continued legalization for medical marijuana. As the restrictions are loosening up you have a pretty big component of pharmaceutical companies that are looking into the properties of marijuana.

However, in the broader picture in Europe, and to a lesser extent in the US, there is a movement centered on indoor crop production and creating huge indoor farming facilities. There is certainly a trend to try and grow more crops and certain types of food indoors for a variety of reasons, such as pest control and environmental control to increase yields.

Agriculture is a much different application than general lighting since in agriculture you are dealing with yield and a measurable, objective quantity. The end users, the farmers, are very much more risk adverse then the general lighting communities. They want to see results and data before they invest and they conduct trial runs themselves. It will be a long adoption process. It will play out very much like municipalities adopting LED street lights.

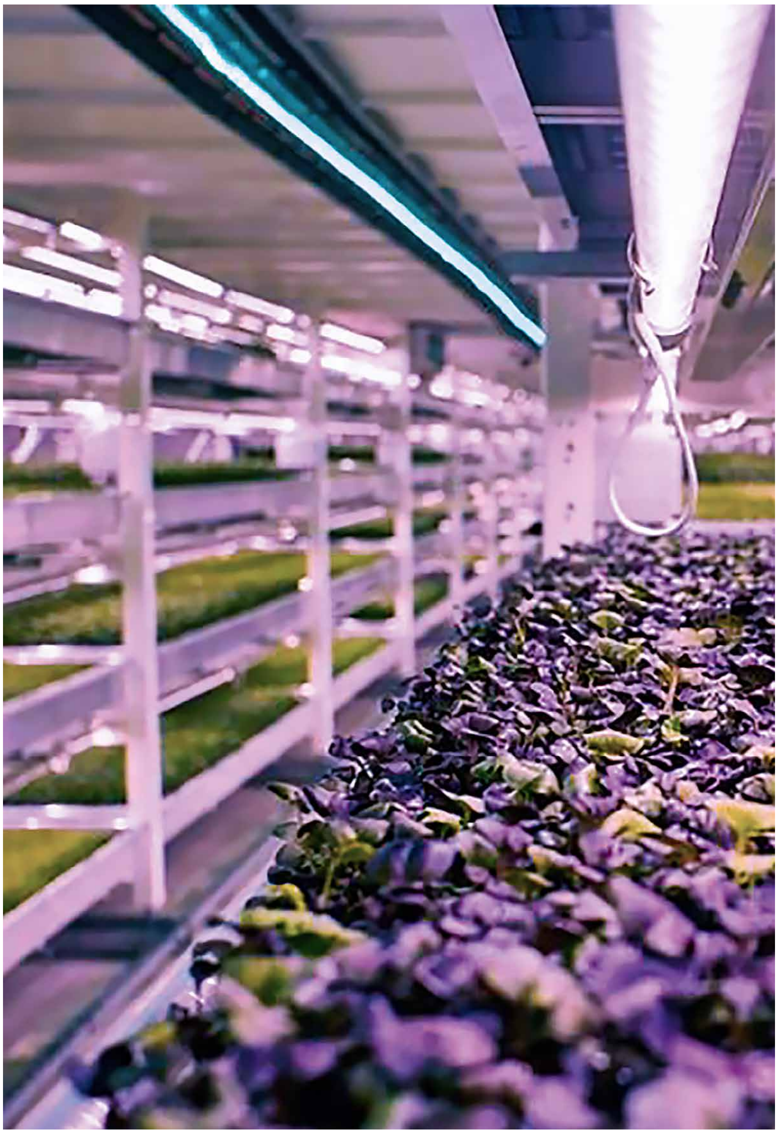
LED professional: Efforts have begun to make the standardization of horticultural processes around installation as well as for creating luminaries. Do you know how far along this process is and if what the plants require has been gauged and referenced for producers to use?

Paul Scheidt: That is a big question. What I can say is that it is the IP that lighting manufactures want to invest in and hold on to. There isn't a lot of public information out there on this for this very reason. These are the fundamental questions our clients want to be able to answer for their customers. Cree, as a supplier to those companies, isn't investing in this type of research.

LED professional: In terms of the market share in general, and in relation to Cree, how important is the horticultural lighting sector?

Paul Scheidt: From Cree's prospective it is still a relatively small application in comparison to other things, such as indoor and street lighting, but there is still a lot of potential as we are only getting started. The LED luminaires coming out this year will be the products that have a clear value proposition in terms of their cost effectiveness and the returns they can offer versus the incumbent technologies. With adoption curves, you look for the point where things go from being something quite small to where they become mainstream, and in horticultural lighting we appear to be

The entire LED industry is focussing more and more on horticulture lighting



getting close to that point. It is still a niche technology but with the changes we are seeing, and as more people invest, mass adoption will follow.

LED professional: What are the real advantages when using LEDs in these applications? Can you tell us about what improvement factors there are in the crops and maybe a little about the products and installation process?

Paul Scheidt: With LEDs we are at a point now that light source efficiency, forget about putting them in a luminaire; just the raw LED versus a raw lightbulb from a high pressure sodium lamp or a florescent lamp, have caught up and have been able to deliver the same sort of efficiency for plant lighting.

Obviously LEDs have had clear advantages in other lighting applications for quite some time but I think that is one of the reasons why LEDs used in this application have taken so long. The light sources used now are pretty efficient and it took a long time to get to the point where LEDs can offer an efficiency advantage.

Right now, once you put them into luminaires a lot of the power saving you see, especially against the high-pressure sodium lamps, really comes from being able to put the light where it is supposed to go.

So it's not like your traditional lighting applications where you can save five times the energy. We are at the point where you can save 20%-30% of the energy depending on the application. That is obviously attractive because we are at a point where LEDs have an advantage of going one to one against an existing light source.

The second major advantage of LEDs is the spectral control they offer, specifically over time, to tweak the spectral content to carry out very specific functions: influencing the shape of the plant, influencing the taste of the edible plants and being able to control disease. These functions were all themes discussed in May at The Horticultural Light Conference.

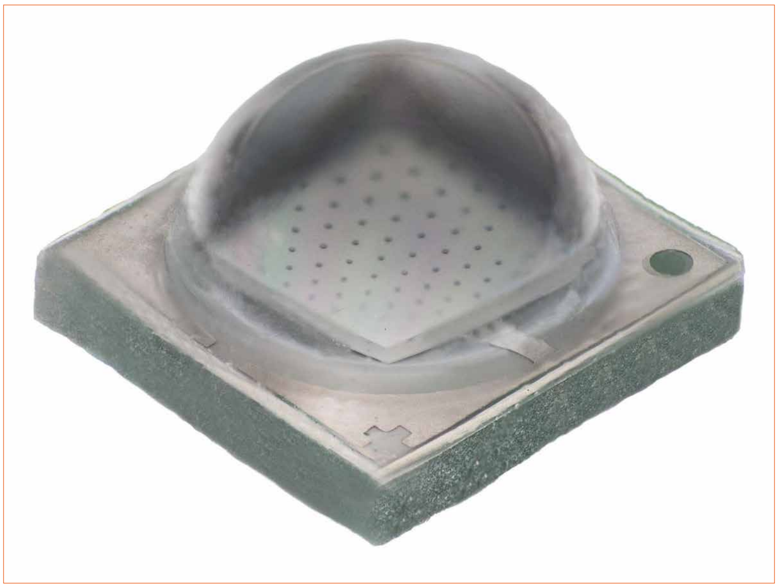
We are at the beginning of figuring out exactly what potential is there. To pull off these kinds of functions requires LED lighting sources, because there is no other technology that can do it.

LED professional: In terms of the efficiency regarding the distribution factor, how important are these dimensions or the form factor of the luminaire when building up production and installation, especially in relation to the heat, as we hear heat is a problem in horticulture?

Paul Scheidt: The heat widely depends on where you are, what season it is and what you are trying to grow. It is similar to the debate that had to happen with LEDs and traffic signals. If you are in a hot climate then you probably don't want the heat, but then if you go somewhere with extreme cold and snow, heat is somewhat beneficial in a traffic signal application to help melt the snow and ice and to increase visibility.

Heat is very contextual as to where you are, what season you are in and what you are trying to grow. Does the crop like heat or does it not like heat? The heat factor is still up for debate, I don't think there is a clear answer. LEDs are what they are; they can generate less heat which can be a good thing for certain plants.

With regards to the form factor of the luminaire, this is a consideration in supplemental lighting. By this I mean adding additional light to an environment, like a greenhouse that primarily uses sunlight, then form factor is an issue. You do not want to create too much shading on the plants. However, there are other environments where the artificial light is the primary light source and in these cases the form factor is not so much of a problem.

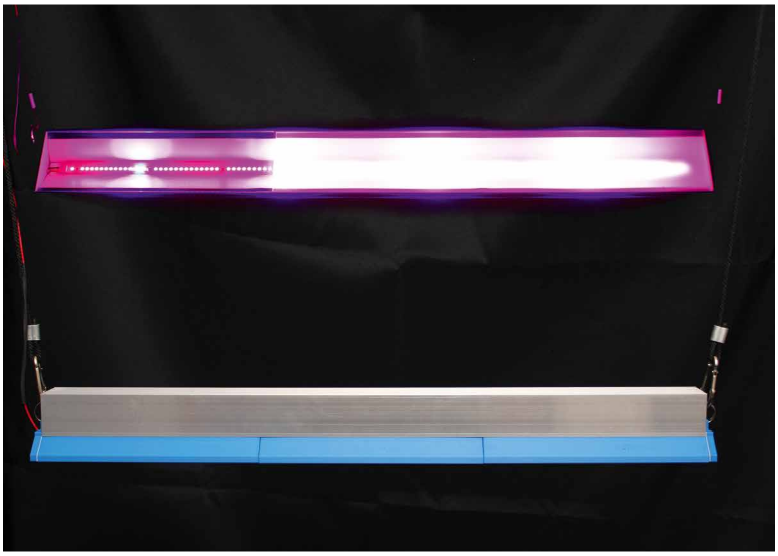


The latest generation of XP-G3 Royal Blue LEDs is an especially efficient horticulture optimized product

LED professional: With regards to the other functions that can be built into plants themselves, such as form and taste, where is the research on this at the moment? How does that knowledge effect future components and do you need new components to cover all these new functions wanted from plants?

Paul Scheidt: It's too early to tell right now. The industry agrees that the research needs to come from the academic institutions. Everyone is looking to the universities around the world to do the fundamental research. I know many of them have been engaged and have been funded to take on these tasks and to try to figure out what the ideal light recipe or growing environments for certain plants is.

A lot of this research is still very fundamental and at its early stages. We are at the beginning of trying to understand it and therefore it is very hard to say at this point in time that there is something very useful about to happen with certain wavelengths. So far, from what I have seen, Reference designs with different properties are already prepared



there have not been a huge amount of people asking for different kinds of wave lengths from those currently available from the LED industry. However, that may change depending on the research that happens.

LED professional: Are there specific spectral ranges that have the greatest effect so far, or is it too early to say?

Paul Scheidt: Again, it depends on the function. There are two specific crops I have learnt about at recent conferences. One was specifically around lettuce production and the growers that are trying to promote a chemical that turns leaves from green to red. They are doing this because it is known to be an anti-oxidant. For the last couple of days before harvest they place the crop under the blue and red light and this promotes the reddening of the lettuce. That is one function where a special LED light combination can increase the value of a crop.

Another example comes from basil crop production. When you grow basil indoors you don't have bugs, but you still have disease. There is a big problem of controlling mildew that grows on the plants and decreases the yield. There is a study that shows if you turn on a red light in the middle of the night it disrupts the cycle of the mildew, in which case you could effectively control disease by using red light. I think we will continue to see more discoveries like this in the future.

LED professional: What future areas of development in the technology itself do you think there might be?

Paul Scheidt: We are already quite far down the road for LED technology. There has already been a huge effort in the LED industry to increase output, decrease costs and improve efficiency. Unlike with the outdoor lighting applications where we started at one efficiency level and now they are double what they were. We are at the end of that curve when it comes to horticulture applications, there will be no doubling or tripling of efficiency. There will be performance gains, but it is not like LEDs will skyrocket!

LED professional: What was the latest component Cree launched and how do you set these different kinds of LEDs together to reach certain spectrums?

Paul Scheidt: The most recent was the XLamp XP-G3 Royal Blue, which is by far the highest output and highest efficiency blue LED available on the market. It can be used in many different applications, but primarily it is for use in the horticulture applications. Cree's approach to the market is pretty similar to the general lighting market in that we have a broad portfolio and many performance classes in order to help our customers to make the luminaire they want. From the performance angle, the XP-G3 Royal Blue is the highest performing LED in the market and it is up to 81% wall plug efficiency.

We also excel at long-term reliability and we carry out extensive LM-80 testing to back up our lifetime promises with data, which suits the risk adverse users. It is incredible how the human eye is exceptional at adjusting to brightness, we marvel at it. The human eye can adjust to a 30% difference in brightness. When you go into horticulture application the light output level directly correlates to the yield that you see in the plants. There is no buffer, when lights dim, the yield goes down. If something degrades very quickly and is 100% for one growth cycle then goes down to 90% for the second growth cycle, you will see a reduced yield. There is no room for adjustments. Traditional LED systems are more expensive then their counterparts, so they have to last.

LED professional: With regards to 2018, what can our readers expect to come from Cree?

Paul Scheidt: I can certainly say there will be more package options as we continue to create more platforms across the board for all applications. We will then be making them work for Horticulture applications. We will keep doing what we are good at, which is enabling our customers with many package and performance options. Cree's strategy is to be a pure component supplier for horticulture and we will be focusing on that in the future.

LED professional: Thank you so much for taking the time to talk to us today and for sharing your thoughts and ideas. There is still so much to discover and look forward to in the application of Horticultural Lighting. The future is set to be exciting and challenging. ■

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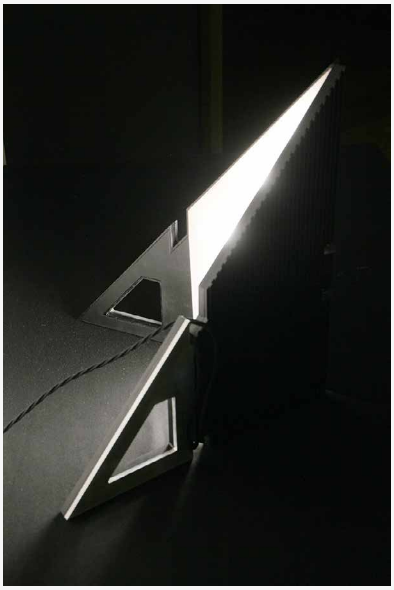

Winner of the SSC "Out of Bounds Design Contest", the Construction Lamp, by Lena Gillitzer

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DESIGN & ENGINEERING
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RESEARCH

"Best Papers" at LpS 2017: Scientific Award Winner Paper

The 4th LED professional Scientific Award will be presented to the author(s) of the best scientific paper at the LpS 2017. The winning paper, which will be presented at the LpS, and printed in the proceedings booklet, will also be published in the 64th issue of LED professional Review for those not able to attend the event this year. ■

Thermal Problems Posed by Compact Packaging and Internet of Things for SSL Systems

Besides general lighting, LEDs are penetrating many areas. At the same time, Internet of Things (IoT) has been rapidly evolving. Added electronics are expected to add an additional 70% to overall heat generation. Therefore, solving thermal problems will become more important again; on a par with footprint area and cost. This paper will present some of the current, local, hotspot thermal issues caused by tight packaging. The severity of the problem for future lighting systems with added IoT will also be presented. Finally, possible technologies to meet those challenges will be shown. ■

TECHNOLOGIES

A New Technology Is Changing the Tunable White Solution

Tunable white is a minimum requirement to providing so-called human centric lighting, or better, biodynamic lighting. A new approach for tunable white solutions is able to provide flexible lighting for multiple occasions without sacrificing output or going over project budget. The authors will compare this new technology, called ColorFlip, to conventional tunable white solutions, and talk about current tunable white issues. ■

ENVIRONMENT

The Environmental Impact of LEDs - Production & Operation

Today, LEDs dominate the lighting domain. They are efficient and manufacturers understand how to implement them for different lighting applications. While energy efficiency is rather well known, what is less understood is the environmental impact of producing LEDs. The article will have a look at the environmental cost of LED production versus the significant energy savings that a full transition to LEDs would bring. ■

EVENTS

LpS & TiL 2017 Post Show Report

In 2017, a new format, Trends in Lighting (TiL) will be co-located with LpS. While LpS still covers all traditional issues of solid-state-lighting technology, TiL gives insight to smart applications, smart lighting, systems and solutions. 100 top speakers will be lecturing at the LpS and the TiL Forum. Furthermore, two new awards were introduced this year. The post show report will give a brief summary of the three days in Bregenz. ■

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