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LED professional Review

LpR

Trends & Technologies for Future Lighting Solutions

July/Aug 2015 | Issue 50

Exclusive Interview: Shuji Nakamura

Event Reviews - Focus on Asia and USA

Color-Tunable, InGaN Nanowire LED Arrays

Lighting with LEDs – More than just Illuminating Objects


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At our joint EBV/Osram booth we will showcase various applications such as:
• A street lamp
• Featuring the latest Osram Oslon Square LEDs with new phosphor technology and a digital driver design
• A color tunable panel light
• Based on Osram's latest Duris S2 CSP-technology simulating daylight over the entire day and hence affecting our circadian rhythm
• A horticultural LED lighting application
• Significantly stimulating plant growth while drastically reducing energy consumption through the use of dedicated Oslon SSL LEDs in far red, deep blue and hyper red
• A surgical lamp
• Featuring the Osram Ostar Medical enabling customers to set the shade of white emitted by the Osram Ostar Medical according to their individual requirements
• within a colour temperature range of between 3,700 and 5,000K, optimized for the red spectrum (R9) at a high CRI of 95
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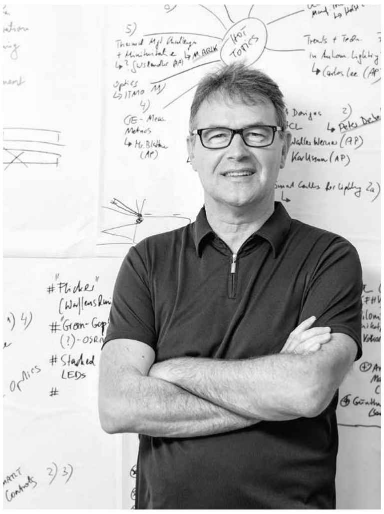


Celebration Issue 50

Luger Research e.U., founded in 2001, is the publishing company of LED professional Review (LpR). The main focuses of the company are Media, Events and Research in the field of solid-state lighting with an emphasis on Trends & Technologies for Future Lighting Solutions.

After the first issue was published in March/April 2007, the LpR rapidly became one of the leading global information sources in solid-state lighting. With a total of over 3,200 pages consisting of more than 400 expert articles and interviews, and hundreds of news-pages, the last eight years have been filled with hard-work and a great deal of enthusiasm. We are proud to have established the LpR publication as an important information source for LED and OLED lighting technologies. This issue contains an overview of all archived issues for your reference.

The occasion of Issue 50 is the perfect time for our team at the headquarters in Dornbirn, Austria, as well as the international sales team to express their sincere appreciation to our more than 25,000 readers for your loyalty and valuable suggestions throughout the development of LED professional. The high quality of the magazine reflects the contributions by countless experts and organizations from the areas of research and industry. And of course, the magazine could not exist without the substantial number of sponsors and advertisers who have trusted us to reach the right audience for their products and services throughout the years.

I believe it is also appropriate to take this opportunity to thank our Editor-in-Chief, Mr. Arno Grabher-Meyer, for his excellent work. Heartfelt thanks also go out to the whole team here in Dornbirn as well as our hard-working representatives around the world for the fantastic work they do on a daily basis.

It was a great honor for us to have the opportunity to interview Professor Shuji Nakamura, inventor of blue and white LEDs and the Nobel Prize winner in Physics for an article in this Issue. I met Professor Nakamura in St. Petersburg, Russia, where he accepted the Global Energy Prize for his outstanding achievements in energy research and technology. His work is helping to address the world's various and pressing energy challenges. In the interview he talks about how he sees the future of solid-state lighting technologies and what the "winning technology roadmap" looks like to him.

Arno Grabher-Meyer was in Asia, gathering information at the GILE in China and LED lighting Taiwan. Dr. Nisa Khan was at the Lightfair International in the USA and wrote a report for us on that. The reports, the commentary from General Secretary of LightingEurope, Diederik de Stoppelaar, as well as premium articles from McGill University, Inkron Oy, Bartenbach and the Holst Centre/TNO can all be read in this issue.

Thank you once again to the many people who have contributed over the past 8 years. We are looking forward to the next 50 issues and deeper and closer collaborations with you!

Yours Sincerely,

Siegfried Luger
CEO, Luger Research e.U.
Publisher, LED professional

ADVERTISING INDEX

Diederik de Stoppelaar

Mr. Diederik de Stoppelaar, a seasoned lighting veteran, brings over 25 years of experience in the lighting industry to LightingEurope, including being instrumental in the founding of LightingEurope and serving as Treasurer from 2011-2013. Previously he was the global General Manager for the Vertical Outdoor within GE Lighting. Prior to his work at GE, Mr. de Stoppelaar has served in various management roles within Philips Lighting, as Chief Marketing Officer of Thorn Lighting, Regional Commercial Director of Zumtobel, and Vice President for Sales, Europe and Africa, of Lutron.

CREATING GROWTH FOR THE LIGHTING INDUSTRY IN EUROPE WITH NEW OPPORTUNITIES

How to create growth for the lighting industry in Europe was the challenge in the strategy workshop of LightingEurope in May. With the economic climate improving, various opportunities around LED technology have been defined including lighting applications such as smart lighting or human centric lighting.

LightingEurope is an association that represents more than 1,000 lighting companies with more than 100,000 employees in Europe. The members of LightingEurope consist of major lighting companies that produce traditional and LED lamps, fixtures, lighting controls and gears and seventeen national lighting associations.

From an EU perspective, LightingEurope is the one-stop-shop for industry input on lighting issues for the European institutions.

Below is a list of the work LightingEurope has done on LED related EU policies:
Innovation: In the EU funded lightingforpeople project, as one of 24 consortium members, LightingEurope leads the human centric lighting and communication package. The project aims to accelerate the uptake of high-quality LED technology in Europe by supporting open innovation and bringing validated information to all relevant stakeholders. The platform is a new information source for interested parties, such as municipalities, universities, architects and industry.

Environment: At the beginning of 2015 LightingEurope submitted 38 requests for ROHS exemption renewals to the European Commission together with 29 industry organisations. LEDs are affected by the use of lead. Lighting Europe is also debating with the European Commission and the European Chemicals Agency about REACH, specifically on innovative substances used in LEDs such as GaAs, InP, rare earths and nanomaterials.

Enterprise: Progress in market surveillance will be achieved with the EU funded EEPLIANT program on eco-design & energy labelling. LightingEurope is an Advisory Board member. Authorities from 12 EU countries will carry out testing and enforcement activities for 100 LED lamp types until June 2017.

For product safety and quality, we have co-developed the ENEC+ mark together with the European Electrical Products Certification Association. This first pan-European mark certifies the initial performance of traditional and LED luminaires.

LightingEurope is working for the proper classification of LED lighting products for customs codes. We fully support the publication of the recent Regulation (EU) No 1037/2014 according to which typical LEDs are covered by tariff class 85.41 with zero import duties.

LightingEurope will be proactively driving digitalized lighting, quality as well as energy efficiency. Lighting joins the ICT world with benefits beyond illumination such as smart lighting and the Internet of Things. We are building alliances with the relevant partners and strive to develop rules on data safety and privacy.

Supporting a level playing field in Europe, quality will continue as a growth enabler with our focus on safety and standardization.

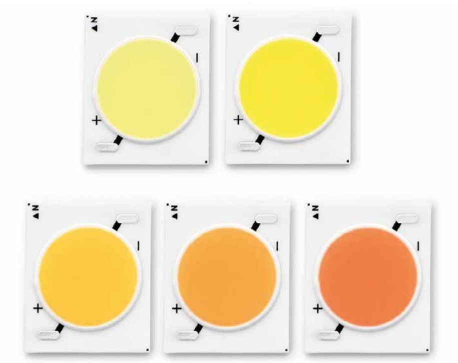
We will exploit energy efficiency by shaping regulations on new eco-design requirements. The main focus will be to contribute to the transition from product based regulations to lighting systems, a combination of interacting light sources, luminaires and related equipment. New statistics from national luminaire data will strengthen our position.

Coming from the LightingEurope strategy workshop, it is obvious that a lot of work still lies ahead. One thing is clear; LightingEurope fully embraces the innovative opportunities around LED technology and will drive the growth of the lighting industry in Europe. ■

D.d.S.

Five Tailored White LEDs from Sharp for Retailers

Sharp Devices Europe has launched a new line of Tailored White LEDs as part of its Mega Zenigata platform. The new models are available as COB LEDs or integrated Intermo modules. Separate LEDs have been specially designed for four grocery applications targeted at the product categories meat, bread, fresh fish and vegetables.



Sharp's new Tailored White CoB LEDs and modules have been specially designed for four grocery applications targeted at the product categories meat, bread, fresh fish and vegetables

As online shopping continues to grow in popularity, retailers with physical locations are eager to enhance their offline retail experiences for consumers. Sharp's latest LEDs are a new way for bricks and mortar stores to truly shine. The new Tailored White family meets the unique requirements of specific products in the fashion and grocery segments by employing innovative phosphor technology and precise wavelength control. These new Mega Zenigatas also deliver high-CRI lighting for outstanding overall color quality with all the efficiency and low maintenance costs LEDs are known for.

The model optimized for grocery meat cases has a CCT rating of 2000 K, with the bread, vegetable and fresh models coming in at color temperatures of 2400 K, 5100 K and 5400 K respectively.

The 3000 K retail version rounds out Sharp's new family of dedicated-purpose, high-CRI LEDs for retailers, giving sparkling whites as well as vibrant colors. Although the Tailored White family claims Ra values as high as 97 and efficiencies up to 97 lumens per watt, it is the innovative matching of the LEDs characteristics to the produce and goods on sale that puts retailers' wares in the best light.

When supplied as integrated Intermo modules, Sharp Tailored White LEDs ensure simple and fast integration into luminaires and lighting designs while reducing development and inventory costs. Sharp Intermo modules attach to the heat sink with just two screws, support a wide range of reflectors, and ship with integrated thermal interface material and solder-free connections. ■

Osram Duris S 10 LED as an Alternative to Low-Lumen COBs

Duris S 10 is the latest addition to the Chip Array SMD family (CAS) from Osram Opto Semiconductors. This new LED is characterized by high efficiency, high light output and uniform color appearance. Efficient SMD technology (surface mounted device) makes assembly simple. These properties lead to significant cost savings in system and optic design, which may be as high as 30 percent depending on the particular customer application.

The new Duris S 10 versions from Osram Opto Semiconductors are interesting alternatives to low-power-CoB LEDs

Technical Data:		
	GW P7LM32. EM	GW P7LP32. EM
Footprint	7.0 x 7.0 mm	7.0 x 7.0 mm
CRI (color rendering index)	80	80
CCT (correlated color temperature)	2700 K - 6500 K	2700 K - 6500 K
Luminous flux (for CRI min. 80, 300 mA, 85° C)	typ. 1050 lm @ 3000 K	typ. 1400 lm @ 3000 K
Forward voltage	28 V	37 V
Beam angle	120°	120°

The new Duris has a compact footprint and is available in two output classes with up to 1400 lumen. It simplifies the design of lamps and luminaires and is ideal for use in spotlights, downlights, and directional and omnidirectional retrofits.

"The new Duris S 10 with its typical luminous flux packages of 1050 and 1400 lumen and a light-emitting surface of only 7.7 mm in diameter forms the basis for compact optics and extremely narrow beam angles", explained Vincent Lee, Product Manager at Osram Opto Semiconductors. The lumen packages have been chosen specifically for standard applications such as MR16 retrofits, and enable lamp and luminaire designs to be created on the basis of a single Duris S 10. This, in turn, helps prevent multiple shadow effects – a clear advantage over the frequently used multi-LED clusters. Both single-spot versions have the same footprint of 7.0 mm x 7.0 mm, offering flexibility in the design of compact luminaires with high luminous flux. Thanks to the small size of the LED, the design of the optics is also simpler, which means that it is easier to integrate standard accessories such as lenses and reflectors.

Both Duris S 10 CAS LEDs are binned according to the familiar MacAdam ellipses, resulting in a more uniform color appearance. In view of the surface-mounted design of the LED, a pc board has to be incorporated in the luminaire. This does, however, open up numerous design options such as integrating thermal fuses, connectors or driver components on the LED board. In standard CoB (Chip-on-Board) solutions up to now, these functions have had to be accommodated on a separate pc board, taking up more space. Compared in particular to these established solutions, the two new Duris S 10 LEDs with their many benefits are excellent alternatives in this luminous flux category. ■

Samsung Electronics Unveils Ultra-Compact CSP Technology LED

Samsung Electronics Co., Ltd., a world leader in advanced component solutions, introduced advanced chip scale packaging (CSP) technology for use in a diversity of LED lighting applications at Lightfair International 2015, held in New York, May 5-7.

Samsung's second generation CSP technology LEDs are approximately 30 percent smaller than the first generation and allow the generation of 2 by 2 or 3 by 3 arrays

Samsung's new CSP technology significantly scales down the size of an LED package, which enables more flexible and compact designs when manufacturing consumer LED lighting modules or fixtures, and lowers the manufacturing and operational costs of a LED lighting system. Samsung's CSP also provides flexibility in adjusting the size of the light-emitting surface and the luminance level, to meet the differing requirements of various lighting fixture applications.

"Our LED chip scale packaging technology will contribute to providing innovative LED component solutions that can overcome the limitations of today's LED lighting market," said Dr. Jacob Tarn, Executive Vice President, LED Lighting Business Team, Samsung Electronics. "We will incorporate the new technology in future Samsung LED products and continue to introduce more advanced LED technology."

The newly introduced CSP technology is actually Samsung's second generation. Last year, Samsung introduced LED package products using its first chip scale packaging technology which featured a versatile new type of flip chip packaging. The first generation CSP was created by flipping over blue LED chips and then adhering a phosphor film to each of them. Unlike conventional LED packages that require a packaging process following the actual chip manufacturing, this allowed chip-scale packages to be created without a mold, enabling more compact LED lighting designs.

Samsung's new, second generation CSP takes the advancements even further. In the second generation CSP, blue LED chips are flipped over and immediately coated with a phosphor substance. The second generation CSP has inherited the advantages of the first generation CSPs, such as freedom from metal wires and plastic molds, which lead to smaller packages, more compact lighting designs, lower thermal resistance and high current availability, resulting in high flux and greater reliability. In addition, using the second generation CSP process makes new Samsung LED packages even more competitive in raw costs, and achieves higher robustness and reliability with a longer life span, as well as higher operating temperatures and current.

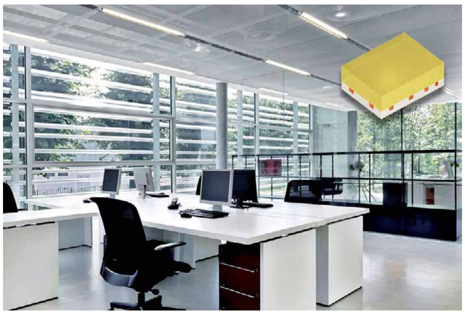
Based on the new advancements, this second generation CSP technology enables LED packages with an ultra-compact form factor: 1.2 mm by 1.2 mm. These dimensions are approximately 30% smaller than the 1.4 mm by 1.4 mm measure of the first generation CSP, while offering a 10% improvement in light performance. It also provides higher light quality with advanced multifaceted phosphor coating technology, which covers the top and four sides of an LED package with phosphor. Because of the small form factor that it allows, the new CSP technology can be used in a wide variety of LED packages for applications that range from ambient light and spotlight, to downlight and bulb lighting.

Moreover, the second generation CSP LED packages can bring even greater design flexibility by offering added delivery options. In the manufacturing process, 2 by 2 and 3 by 3 CSP arrays can be easily created and offered to customers, depending on a diversity of market needs. The availability of CSP arrays provides not only more design flexibility, but also better light quality in each LED luminaire through their one-lens design, in which the CSP arrays share a single lens instead of having to use individual lenses for multiple conventional packages.

The second generation CSP technology is expected to be applied to new LED packages in the fourth quarter of this year.

Osram Duris S2 LED for Fluorescent Tube Replacement

Osram Opto Semiconductors is extending its Duris product portfolio with a compact version without a classic package. The Duris S2 is in the low to middle output range and offers a high typical luminous efficacy of 160 lm/W, excellent color homogeneity and color stability. It is therefore capable of achieving homogeneous illumination in LED products designed as replacements for fluorescent tubes.



The new Duris S 2 from Osram Opto Semiconductors, which is the smallest LED in this product family, is ideal for replacing fluorescent tubes

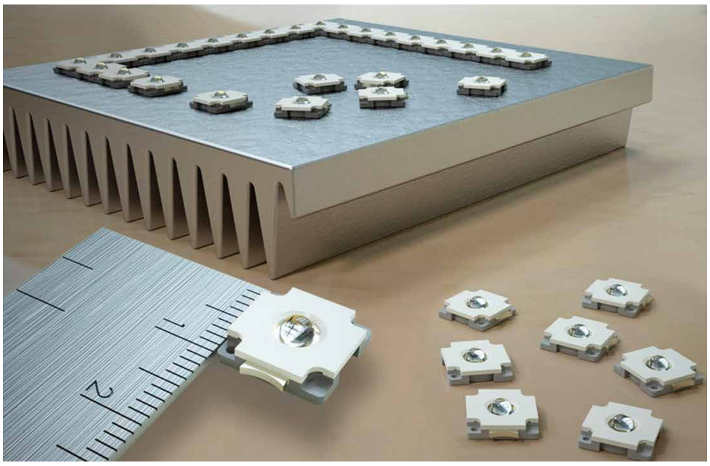
Thanks to its compact footprint of only 2.0 mm x 1.6 mm, this space-saving LED is ideal for linear lighting solutions. With an emission angle of 150°, this chip-size LED emits more light to the side than LEDs with classic packages. The light is therefore better distributed in linear lamps and luminaires, and hot spots (visible points of light) are reduced. This, in turn, enables the number of LEDs, and therefore, costs also to be reduced. By overdriving the LED up to 150 mA the range of applications for the new Duris S 2 can be extended to recessed ceiling luminaires and panel luminaires.

The S 2 is the first Osram LED to use a new lead frame material, an epoxy molding compound (EMC). "Thanks to this material the Duris S 2 has a longer life of up to 50,000 hours", said Tony Tam, Project Manager at Osram Opto Semiconductors and responsible for the Duris product family. This is more than that of the existing Duris products such as the sister LED Duris E 3, which has a lifetime of 35,000 hours. "Other products featuring this technology will follow", added Tam.

Measuring only 2.0 mm x 1.6 mm, the S 2 is the smallest LED in the Duris family. The new product now joins the existing S versions. The new Duris S 2 is available in different correlated color temperatures: 3000, 3500, 4000 and 5000 K. From summer 2015 additional versions with color temperatures of 2700 to 6500 K will follow. The new LED is currently being subjected to extensive quality testing. The certification process based on the LM-80 standard (Energy Star) is in progress and the results are likely to be available in the winter of 2015/2016.

Litecool Introduces Lumen Block™ PCB-Free LED Package

Litecool, a leading innovator in LED packaging and thermal performance, announced that it has filed a patent on a PCB-free LED package known as Lumen Block™ which will be available soon. This new technology enables the assembly of LED arrays with no circuit board putting the LED package directly on the heat sink for ultimate thermal performance and cost reduction.



Litecool's Lumen Block™ is an LED package that doesn't require any circuit board, enhances performance and reduces costs for luminaire manufacturers

Litecool's Lumen Block™ is an LED package that can connect directly to the next LED package without the need for a circuit board to hold it or provide connections. They can be placed directly onto a heat sink and automatically clip together forming mechanical and electrical connections. That means no soldering, no PCB and direct thermal connection to the heat sink.

This technology is set to shake up the existing supply chain by removing the need for PCBs and SMT assembly. Litecool takes bare chips from die manufacturers and puts them in their package that they supply directly to luminaire manufacturers who can then simply place them on their heat sinks. This shortened supply chain means the system is more easily optimized for specific applications and reduces time to market for new products as well as reducing costs.

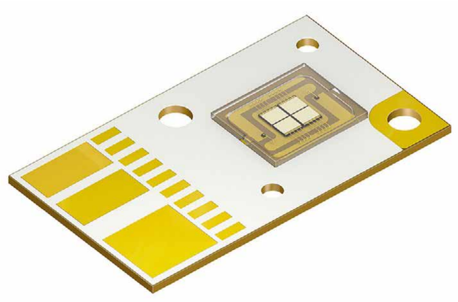
"At Litecool we like to enable higher performance and lower cost luminaires. Our technology so far has doubled lumen density for our customers giving significant system cost saving. The Lumen Block will take this a big step further removing MCPCB materials and SMT assembly from the LED array making it fast and easy for luminaire manufacturers to arrange LED arrays with a simple pick-n-place machine." James Reeves, CEO, Litecool.

"Instead of trying to reduce the thermal resistance of an individual component in a system, we ask ourselves why these components were in the system at all. By removing the circuit board form the system we can optimize cost and performance. The Lumen Block is the collimation of Litecool's technology optimizing thermal performance and manufacturing." Elwyn Wakefield, Chief Packaging Engineer, Litecool.

The Lumen Block™ will be available with a variety of LED die inside giving a choice of performance. First product will be a 10mm x 10 mm package containing a Cree Gen 3 LED capable of nearly 150 lm/W. The packages will fit standard optics from Carlco giving a range of high efficiency beam patterns. ■

Osram's New Ostar Projection for Continuous Trouble-Free Operation

Osram Opto Semiconductors presents P2W 01, a particularly reliable addition to its familiar Osram Ostar Projection series. This new LED contains four chips which can be controlled in two separate groups. The LED therefore represents an integrated solution which, in the event of emergencies, offers trouble-free operation in safety-related and security-related applications such as control room monitors.



The new Osram Ostar Projection has four chips which can be controlled as independent pairs

"The redundant system of the new Osram Ostar Projection is ideal for 24/7 applications. If a chip should ever unexpectedly fail, the second system will continue to operate without any problem at all", said Wolfgang Schnabel, Product Marketing LED at Osram Opto Semiconductors.

Up to now, only the chips in the large Osram Ostar Projection P3W could be controlled separately. This is now also possible with the P2W 01. Osram Opto Semiconductors has developed a compact LED with two self-contained parallel systems with two chips each. The connection design has also been improved, from 2-pad to 3-pad. This means there are now three connections instead of two. All four chips occupy one pad, the other two pads are each reserved for a group of two. "A new soldering process ensures that the heat produced in the application remains low. The connection between the chip and the package can therefore withstand a lot", added Schnabel.

Compact solution with vivid images:
The high-current chips in the new Osram Ostar Projection are based on the most advanced thin-film and UX:3 chip technologies. They produce high luminance, resulting in extremely bright and vivid images in the relevant applications. The new LED therefore enables lighting solutions to be more compact than before because a smaller active surface is needed to achieve the same light output. Customers who are currently using the P2W can easily upgrade their design to the new Osram Ostar Projection because the size and the optical and technical data correspond to those of the P2W version. Connectors and other accessories are widely available on the market.

The new LED will be used in particular as a light source for back projection systems. This involves projecting the image onto a screen with the aid of reflective optics. Often such systems are designed without borders. Multiple systems are arranged seamlessly next to each other, creating a large borderless screen on which one image can be shown or a different image can be shown on each screen. These systems are used predominantly in the security sector where 24-hour operation is needed, for example, in control rooms for subway stations, railroad stations and underground car parks, and also for major events and industrial plant control. ■

Lextar Electronics Launches DCOB LED Light Engine

Lextar Electronics, the LED vertical integration manufacturer, has launched a DCOB (Driver on COB) product, using Lextar's in-house high voltage Chip to design an integrated light module without an external driver, providing the most convenient plug-and-play LED light engine for the traditional lighting fixture manufacturers. Lextar presented a complete series of AC-in Driver-on-Board module at Guangzhou International Lighting Exhibition from 9^{th} to 12^{th} of June, 2015.

DCOB LED Light Engine from Lextar Electronics

Lextar's DCOB light engine module integrates the previous LED Driver with COB. Since the DCOB is powered directly by the AC power, it can be simply plugged into the power source to light up without the electrolytic capacitor. It improves the lifetime of the light source and increases the product reliability significantly, using the HV Chip manufactured by Lextar.

Lextar Electronics' DCOB light engine integrates the optical and electrical components on a single module. It features small size, ease of use and improvement of lighting design flexibility, suitability for spotlight, down light or bay light fixtures. Lextar's DCOB series are compatible with Zhaga Book 3 specification to facilitate the lighting manufacturers in replacing the COB lighting source directly with no switching costs. In addition, Lextar can also provide customized services for the products from various customers.

Mr. Francis Wong, Deputy Vice President of Lextar Electronics Lighting Business Unit said that traditional lighting manufacturers are constrained by lack of technical personnel in the electronic/electric related fields. Thus, they often encountered photoelectric matching problems when integrating into LED. With the photoelectric integrated DCOB light engine, the lighting manufacturers simply need to add the lighting fixture casing to complete the assembly. That not only solves the technical problem of photoelectric matching, but also reduces the lighting assembly costs. The complete series of AC-in Driver-on-Board Modules includes a circular DOB for ceiling or flush light or downlight, DCOB for track light or spotlight, Linear DOB for streetlight or panel light, that are suitable for a variety of indoor, outdoor and different power lighting applications. The complete series of light engine has many characteristics including but not limited to one-piece compact design, small in size and long lifetime, to provide the traditional lighting customers with the most convenient application of LED photoelectric solution. ■

Bridgelux Launches New Integrated Smart Module LED Array

Bridgelux, a leading developer and manufacturer of LED lighting technologies, debuted the first of its integrated smart module suite of products at the 2015 Light Fair International Conference in New York. Bridgelux's Xenio product is compatible with a greater variety of standards, protocols and other technologies to ensure ease of integration, greater value and future functionality. With the launch of its first smart lighting product, Bridgelux is leading the industry's evolution to integrated, smart light sources and enabling its customers to provide networkable LED arrays for the commercial, retail and industrial spaces.

Advantage	Features
Applications	Xenio enables our customers to provide smart networkable LED arrays for these industries
Communication Options	Standard Module: DMX 512, 0-10 VDC With Optional Comm Module: DALI®, ZigBee®, Harvard EyeNut, Bluetooth® Smart
Lumen Packages	2,000 to 10,000 lumens 13, 18 and 29 mm arrays
Dimming Quality	Flicker free dimming to 0.1% Configurable dimming curve – logarithmic, linear or custom
Onboard Intelligence	Fixture health monitoring and data archive Dynamic tuning
Simplified Fixture Assembly	Compatible with existing optics Zhaga compatible mounting holes Robust, versatile design
48 VDC Power	Multiple options including In-fixture constant voltage power supplies Power over Ethernet (PoE)

Bridgelux Xenio™solution brings together Bridgelux's hardware and Harvard's EyeNut technology to deliver individual control with individual modules, wirelessly

The Xenio smart platform features tightly integrated controls, local intelligence and communications capabilities, and smooth dimming down to 0.1 percent of light output. In addition, the product delivers superior light quality and the highest efficacy integrated module now available on the market. Bridgelux worked with key technology partners and customers to include compelling features in this new platform to meet the demands of ease of integration, performance, light quality and value required by luminaire manufacturers and their end customers.

"Bridgelux is rethinking what it means to be innovative in the lighting industry," said Brad Bullington, CEO of Bridgelux. "For our customers to succeed in a connected, data-driven future, we're introducing new technologies that are integrated, efficient and compatible, that will position smart lighting arrays as the infrastructure to further enable the Internet of Things. This first generation product sets the tone for how Bridgelux is innovating through hardware and software to deliver compelling value propositions."

A truly open platform, the Xenio smart lighting array is designed to be compatible with multiple communication protocols including Bluetooth® Smart, Zigbee®, DMX 512, DALI® and common controls standards including 0-10 V. The product has also been architected to enable advanced software, offering integration with Avi-on's Bluetooth based system as well as Harvard Engineering's EyeNut platform. These systems offer users the freedom to commission, configure and readily control their own lighting to optimize energy savings and the lighting experience.

"The Xenio platform brings together Bridgelux's technology with Harvard's EyeNut to enable point control with individual modules, wirelessly - a benefit that no other smart lighting product on the market can currently claim," said Antony Corrie, Vice President of Harvard Americas. "By integrating Harvard's technology with Xenio, the EyeNut solution can be used across a wide range of industry and commercial applications, driving unique value for each."

Available in three array sizes, the smart lighting array self-monitors its real-time health and temperature and stores historical operating data in order to optimize performance and value with status reporting that is DMX 512/RDM capable.

The product is powered by the emerging 48 VDC standard, increasingly popular for its high efficiency while still being regulated as low voltage. This forward looking standard offers multiple options for powering light fixtures. The Xenio solution features multiple options for 48 VDC power supplies including fixture integrated constant voltage power supplies, a room level power hub with Class 2 cabling that uses low voltage to power eight to ten fixtures and a Power over Ethernet (PoE) data switch.

The product's open, integrated platform is architected to help future-proof luminaire designs for easy, cost effective upgrades to future Bridgelux smart lighting products featuring, for example, innovative tunable white capabilities, sensor technology or other data-focused innovations. ■

Xicato XTM 9 mm for Narrow Beams and High Center Beam Intensities

Xicato, a leading manufacturer of intelligent light sources, announced today that it has expanded its XTM product portfolio. The new module features a 9 mm light-emitting surface (LES) that enables the narrow beam angles and high center beam intensities that lighting designers require, especially for retail, hospitality, and museum applications.

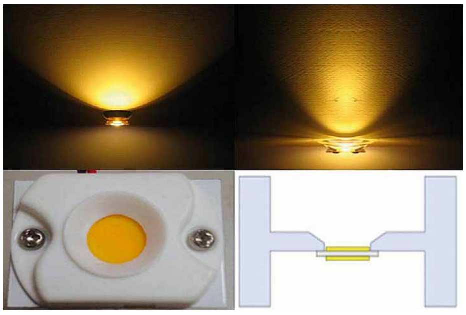
Xicato's new XTM 9 mm LES allows for designs with narrow beam angles and high center beam intensities

"Our 9 mm XTM module produces the lit effect designers have requested and the color quality, consistency and longevity that is expected of Xicato products," said John Yriberri, Vice President of Business Development. "We have been asked by lighting designers to enable tight beams with a high center beam punch. With the XTM 9mm we can achieve 15,000 candela from a 50 mm diameter optic and over 70,000 cd from a 111 mm diameter optic. This is industry leading performance that allows specifiers to address many more applications."

Xicato will offer a full range of 9 mm XTM options for light, correlated color temperature and luminous flux. Efficiencies will be as high as 90 lumens per watt and CRIs up to Ra 98 for the Artist Series. ■

LeDiamond Opto Double Side Emitting LED Product Portfolio

LeDiamond Opto Corp, a leading double side emitting LED manufacturer from Taiwan, has announced its new Tesla 1010 module. Tesla 1010 is a round shape double-side emitting LED product which is suitable for lighting fixtures that need direct and indirect lighting output, such as mini pendant or wall lamps.



LeDiamond Opto's new Tesla 1010 can be used to design double side emitting luminaires

Tesla 1010 (Dimension: 7.3 x 2.2 x 1.1 mm, LxWxH) can be applied to design lighting fixtures by using lens or reflectors to perform different angles in lighting output up and down with reliable performance. It can be easily used for secondary optical design and the required heat sink space is smaller with no limitation as applies to the appearance of the lamp.

Single LED module performs double side emitting light output with advantages in easy assembly, smaller dimensions of required heat sink and low production cost.

The lighting output of each module is 2 W / 300lm @ 14 V / 150 mA without heat sink, and 4.5W / 500 lm @ 15 V / 300mA with heat sink. One Tesla 1010 replaced two pieces of traditional COB performing in the same luminance, but using less power. ■

Quantum Materials - High-Heat Tolerant QDX™ Quantum Dots

Leading North American quantum dot manufacturer Quantum Materials Corp. has launched their new QDX™ class of high-stability Cadmium-free quantum dots at the Society for Information Display (SID) Display Week 2015 International Symposium in San Jose, CA.

Quantum Materials QDX Quantum Dots are characterized by an improved molecular stability allowing higher working temperatures

QDX™ Quantum Dot production is underway on Quantum Materials' patented continuous-flow production system and assessment quantities have already shipped to the Company's largest potential customers.

"Our QDX Quantum Dots represent a game-changing development in advancing next generation display and lighting applications," said Quantum Materials Corp. CEO Stephen Squires. "Their stability under high heat allows for more effective high temperature dispersion onto LCD display thin-film. In Solid-State Lighting, QDX Quantum Dots used in QD-LEDs will give better performance and effective life in high-heat and moisture-laden environments without degradation. We are excited to see QDX Quantum Dots unleash the engineering and design teams of our customers to facilitate advances in display and lighting applications never before possible."

For Quantum Dot Liquid Crystal Display (QDLCD) manufacturing, QDX™ Quantum Dots reduce the need for expensive barrier films currently needed to prevent quantum dot degradation from moisture and oxygen. Custom characteristics can also be incorporated into QDX™, including large Stokes shift to reduce re-absorption loss for increased luminescence and better color purity.

Quantum Materials also expands into new lab space, ramps up second patented continuous-flow production line, reaches QDX™ heat resistance to 260 degrees Celsius and ships QDX™ trial orders to six of the leading global display and television manufacturers

Ongoing environmental testing of the Company's new line of QDX™ Quantum Dots has also obtained heat resistance to 260 degrees Celsius, an important benchmark opening the implementation of Quantum Dots into new solid state lighting solutions due to the high-heat resistance required for casting Quantum Dots in the LED manufacturing process.

Interest in the Company's QDX™ Quantum Dots from display manufacturers has been high as testing has shown that QDX Quantum Dots do not degrade under exposure to the elevated temperatures typical during encapsulation in resins, silicones and other polymers. In display

applications this enhancement can enable the use of lower cost protective films. To address this market need, Quantum Materials has shipped QDX™ trial orders this week to six of the leading global display manufacturers to support ongoing market-driven joint development efforts.

“Our capacity expansion has been implemented at just the right time as demand for QDX™ takes off,” said Quantum Materials Founder and CEO Stephen Squires. “We recognize the hurdles required to integrate Quantum Dots into exciting new display and lighting applications and our scientists’ focus on engineering the appropriate characteristics into our offerings is yielding solid and tangible results. We are particularly pleased with achieving heat resistance to 260 degrees Celsius, which not only fulfills display market demands, but also opens up the entire LED lighting market to Quantum Dot integration.”

QDX™ Quantum Dots are ideal for LED lighting development because they are more stable than organic phosphors and their high heat resistance enables better LED manufacturing capability, high illumination performance, long lifetime and resistance to power spike damage. Solid-state lighting made with QDX™ LED’s offer the opportunity to reduce heat sinks, remove bulky features, and bring innovative and clean form factors to the evolving lighting market.

Tailor-Made Drivers for Chip-on-Board LEDs

The new RCOB LED driver series from RECOM has specifically been developed to meet the requirements of COB (chip-on-board) LEDs. The driver series includes 11 models with output voltages between 25 and 44 VDC and constant output currents of 350 to 1050 mA, thus offering a suitable driver for virtually any application.

The RCOB drivers are surprisingly affordable, come with active PFC (>0.95), and achieve efficiencies of up to 90%. Thanks to their compact and flat design (106 x 67 x 22 mm), the drivers can be integrated into any type of lighting system. The fact that the inputs and outputs are located on the same side of the driver makes installation even easier. The drivers of version RCOB-A come with a 1 to 10 V input and can be dimmed from 0 to 100%.

RECOM’s new driver series, RCOB, is designed to the parameters of COB LEDs

As the new driver series has been designed for the European market, its input voltage is 230 VAC (198 to 264 VAC). The permissible operating temperature range is -20°C to +50°C. A number of safety features protecting the devices against short circuits, overload, overvoltage, and overtemperature ensure maximum availability and reliability. The RCOB LED drivers come with a 3-year warranty.

Mean Well Introduces IP67 Grade Economical 100 W LED Power Supply

The economical LP family launched by Mean Well has been widely adopted by the economical LED lighting fixture market. For constant current (C.C.) output applications, this family has offered a complete product line - LPLC-18/LPHC-18 (18W), LPC-20(20W), LPC-35(35W), LPC-60(60W) and LPC-150(150W).

In order to make the LP family more exhaustive, Mean Well is pleased to unveil the 100 W constant current output LED power supply LPC-100 series.

Mean Well’s new LPC-100 LED power supply is an economical constant current solution with IP67 sealing

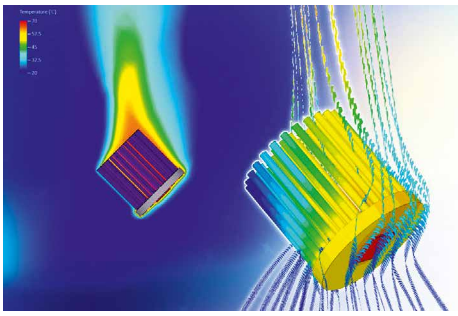
Features:

- 90 to 264 VAC input
- Constant current (CC) output
- High efficiency up to 90%
- Fanless design, cooling by free air convection
- Working temperature: -25 to +50°C
- IP67 design
- Class II power unit (no FG)
- Exploits 94V-0 flame retardant plastic case
- Protections: Short circuit /Over voltage
- Approval: CE
- Dimension(Lx W x H): 190 x 52 x 37 mm
- 2 years warranty

This series is approved for IP67 protection level that it can effectively protect the internal electrical components from dust and moisture damage. In addition, it is equipped with short circuit protection and over voltage protection functions. LPC-100 is truly suitable to be applied to every kind of the C.C. mode LED lighting related applications, such as decorative lighting, recessed light, spot light.

MechaTronix Launches Advanced LED Pin Fin Coolers for Tilted Spots

With the advantage of pin fin LED coolers under tilted position, MechaTronix announces 2 more diameters available as standard. This second-generation pin fin cooler was developed for optimized free air convection under tilted positions of spot and track lights over 45 degrees. Typically, under heavy inclined positioning, LED coolers need a far more open structure at the side to prevent obstruction of hot, rising air.



MechaTronix advanced pin fin coolers with 67 mm and 86 mm promise a performance gain of up to 30% compared to existing cooling platforms

MechaTronix is keen on developing situation specific LED coolers per LED brand, and offers optimal performance that exceeds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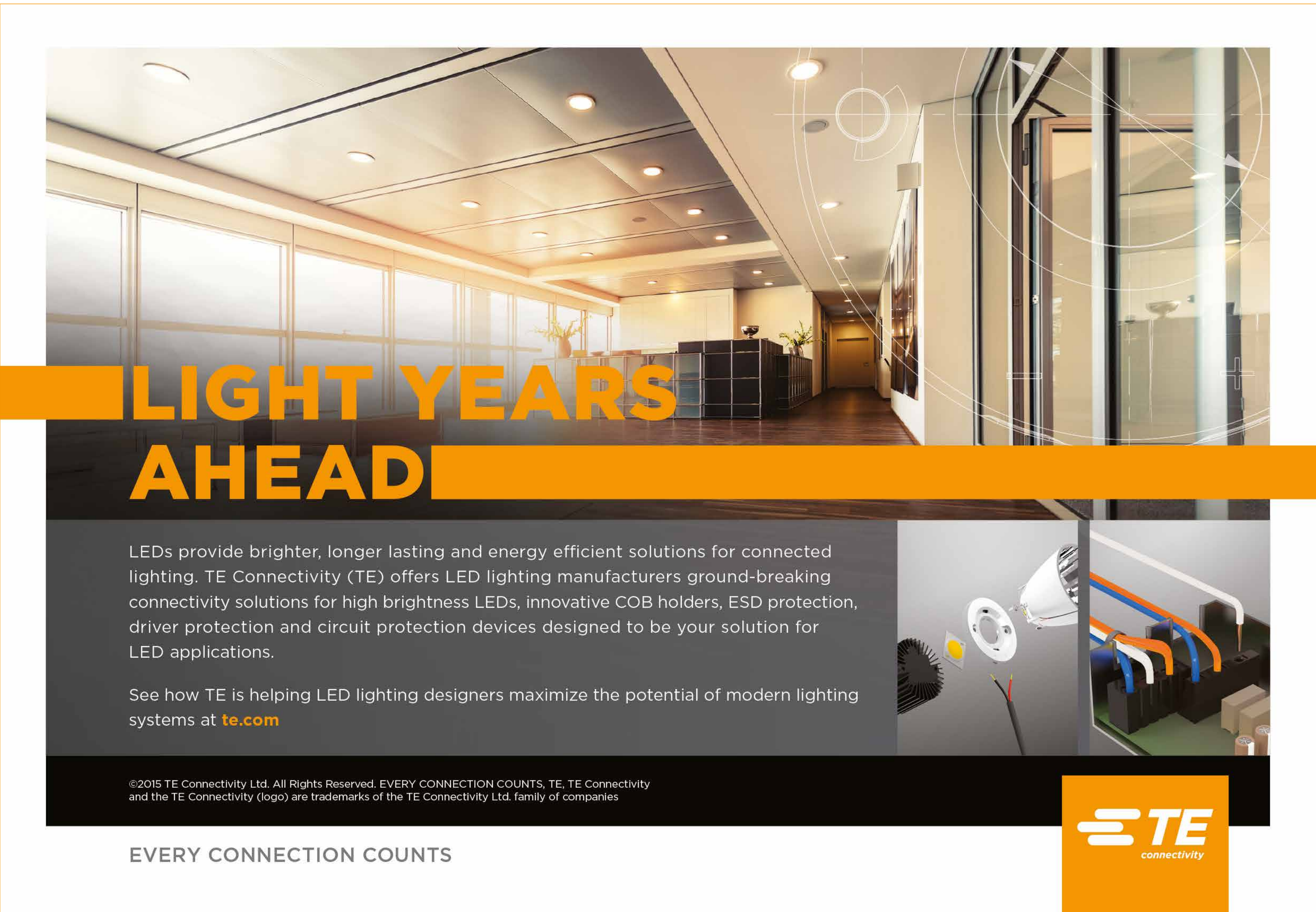
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existing cooling platforms by over 30%. As an example, they launched the LPF67 and LPF86 advanced pin fin coolers. In a diameter of 67mm and 86 mm, these advanced LED coolers keep 3500 lumen and 4500 lumen spot and track lights on the required case and junction temperature even under full horizontal 90 degrees positioning.

The LPF47 and LPF67 advanced LED pin fin coolers are standards foreseen from Zhaga book 3 and Zhaga book 11 mounting holes, as well as an advanced pattern for direct mounting of COB LED modules. Besides better performance under tilted positioning, the weight of these LED pin fin coolers is far lower than extruded star shaped LED coolers with similar performance. The diameter of 86 mm was typically chosen during development to create a 3000 to 4500 lumen passive replacement for tilted active cooled track and spot lights from the past. A few months ago, MechaTronix launched a similar, 86 mm diameter star shaped LED cooler, the ModuLED Micro, for similar replacement of active cooled spot and down lights under vertical position. Now with this next generation pin fin cooler it seems active cooling is completely banned in spot and down light applications.

MechaTronix Launches 5,000 lm LED Cooling in just 20 mm Height

With the current lumen boost of many tier 1 LED manufacturers, the demand raised exponentially for ultra-low profile LED coolers for use in height restricted down light applications. Although the increase in lumen per watt and internal efficacy of recent led COB modules has made the use of passive LED cooling much more likely, most standard LED coolers in the market aimed for classic designs where the cooling surface was created by a smaller diameter with a bigger height.

MechaTronix now launches the ModuLED Mega 13420. With a diameter of 134 mm and a height as low as 20 mm, this LED cooler performs thermal resistance of 1.32°C/W or the equivalent of 5,000 lumen.

Just 20 mm high, and with a diameter of 134 mm, MechaTronix's new LED coolers can easily handle 50 W LED modules

The challenge in this ultra-low LED cooling profiles comes from the spreading of the heat source to the rest of the design. Creating enough basic cooling surface in a wide diameter low profile LED cooler is not that hard. But the LED COB areas have been shrunk over 40% in the last two years to obtain an easier light image control with secondary optics. Also the power density on that area has significantly increased from 25 watts in a 28x28 package to 50 watts and more. With this major change in light engine approach, the spreading resistance of a low-profile LED cooler becomes the focus point to guarantee the life span of the lighting design.

Through advanced thermal engineering and hundreds of hours of thermal simulations, MechaTronix has reached their ultimate goal on this 20 millimeter low profile: A maximum temperature drop of 3 degrees Celsius from the heart of the cooler to the outer diameter cooling area, equivalent for the perfect internal spreading resistance.

To avoid extra costs by after work, the ModuLED Mega is again foreseen from the ground-breaking modularity on mounting holes that allows for very easy attachment of a great number of market-leading LED engines. Looking at the specific purpose of this LED cooler to create ultra-low down light applications with higher lumen packages, MechaTronix has added the Zhaga platforms andsome extra mounting pitches on this design for the Tridonic Talexx FLE and DLE, Osram PrevaLED Cube, Philips Fortimo DLM and a further score of tier 1 LED manufacturers.

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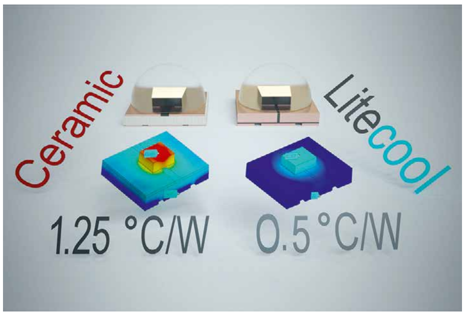
Litecool Turns LED Packaging on Its Side

Litecool has produced LED packages in a vertical orientation rather than horizontal. This means that the dielectric layers only have a minor impact on the thermal performance of the LED package and allow the heat to escape more effectively through the metallic parts of the package. This has significant benefits for flip-chip packaging where dielectric layers are usually very close to the diode.



Litecool's new packaging concept significantly reduces the thermal resistance of LED packages by using a vertical dielectric

Dielectrics are used within LED packages to isolate electrical tracks but they hinder the thermal path causing the LED to overheat. In the construction of conventional LED packages the electrical tracks and dielectrics are layered horizontally. This means the heat has to pass through one or more low-conductivity dielectric layers causing thermal bottlenecks. By turning this layering by 90°, the heat can travel down through the copper tracks and not through the dielectric. The thermal resistance [°C/W] of packages produced in this way is 3 times lower than conventional packaging. This lower thermal resistance means that heat sinking requirements are reduced and the LEDs can be driven much harder for more light output.

The Vertical Dielectric technology (Patent Pending) allows for close packaging of multiple LEDs within one package with minimal effect on thermal performance as well as significant reductions in the thermal resistance of flip-chip packages. The 'track and gap' constraints of traditional electronics manufacturing are removed, allowing for more flexibility in thermal design.

One of the key commercial benefits is that the dielectrics no longer need to be expensive ceramics. Cheaper polymer based dielectrics can be used as their thermal impact is negated. Litecool has developed designs and manufacturing processes to allow such packages to be manufactured in high volume.

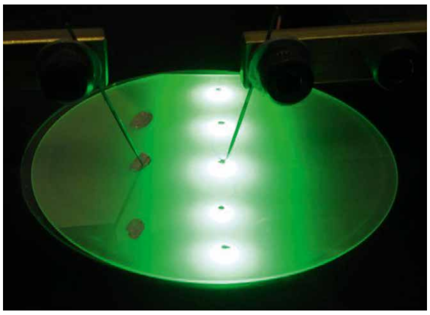
"The location of low thermal conductivity materials is extremely important. The closer they are to the heat source the greater their effect on thermal performance. By changing the orientation of the first dielectric layer it greatly reduces the thermal resistance of the package allowing the heat to flow more easily." Dr. Andrew Young, Sheffield Hallam University.

"It was apparent during design phases of our packages, especially flip-chip packages, that the first layer of dielectric was really impacting on performance. So we flipped it by 90°. This allows for much thicker copper tracks to take the heat laterally away from the LED and reducing the thermal resistance of any subsequent components in the system." James Reeves, CEO, Litecool.

"It is not a difficult concept to design but it is difficult to manufacture. We have had to develop new manufacturing processes to allow for the unprecedented track and gap ratios required and it has resulted in performance way beyond anything else on the market." Robert Corbin, Project Engineer, Litecool.

BluGlass - Improved Performance for Green RPCVD p-GaN LEDs

BluGlass has succeeded in its initial experimentation of applying low temperature RPCVD p-GaN to Green LED applications with highly promising results. These results show that the green LEDs produced using RPCVD p-GaN are demonstrating greater efficiency than the BluGlass grown MOCVD benchmark LEDs using the exact same MOCVD grown multi-quantum wells (MQWs), the critical light emitting region of an LED device.



Green light emission from RPCVD p-GaN layers grown on MOCVD MQWs

Electroluminescence Data (Wafer Quick Test)	At 20 mA	At 50 mA
Light Output (mW)	0.9	2.5
Vf (V)	3.5	4.5
Peak Wavelength (nm)	520	517
Full Width at Half Maximum (nm)	33	37

This indicates that the RPCVD process' low temperature benefits are helping to improve green LED device performance through the reduced degradation of the temperature sensitive MQW layers.

BluGlass' Chief Operations and Technology Officer, Dr. Ian Mann said, "This is great early performance data, which we expect to continue to improve further; especially given that BluGlass has only recently attempted growing green MQWs using MOCVD. Our recent focus has been on optimizing the quality of the RPCVD p-GaN overgrowth process.
It is very encouraging that for the first time, in a side by side RPCVD p-GaN versus MOCVD p-GaN overgrowth experiment, to show that RPCVD has provided a performance edge in LED efficiency."

Dr. Mann added, "The significant efforts in improving blue LEDs over the last 12 months has shown to be readily transferable to the efforts in green LEDs."

At the Company's AGM at the end of 2014, BluGlass outlined its intentions to expand the RPCVD research into new, high growth market applications with strong potential for a low temperature deposition technology such as power electronics, green and yellow LEDs and UV LEDs. The value of this action was recently reconfirmed by Veeco Instruments Inc, asking to evaluate the RPCVD p-GaN for both green LEDs and power electronic applications.

Green LEDs are important for RGB (Red, Green and Blue) LED applications that enable the device to have full color control. The LED industry is very interested in the possibility of a cost effective RGB solution to create more natural looking light and is expected to be popular for segments of the general lighting market.

The value proposition for RPCVD for green LED applications is similar to that of high brightness blue LEDs. The low temperature process is expected to offer performance advantages; however the value proposition is even greater for the green LED market opportunity. This is because green LEDs require high indium content MQWs and therefore benefit from a lower temperature growth process. Low temperature growth enables both; less degradation of the MQW, and provides higher indium concentration (the core material required to create the green wavelength). While RPCVD grown green MQWs have not yet been demonstrated (the results presented to date are for MOCVD grown MQWs) we believe the combination of an all RPCVD grown MQW and p-GaN is compelling from a performance and cost perspective.

Super-Hydrophobic Glass Coating Benefits - Maybe Also for Lighting

A moth's eye and lotus leaf were the inspirations for an antireflective water-repelling, or superhydrophobic, glass coating that holds significant potential for solar panels, lenses, detectors, windows, weapons systems and many other products. The discovery by researchers at the Department of Energy's Oak Ridge National Laboratory, detailed in a paper published in the Journal of Materials Chemistry ©, is based on a mechanically robust nanostructured layer of porous glass film. The coating can be customized to be superhydrophobic, fog-resistant and antireflective.

"While lotus leaves repel water and self-clean when it rains, a moth's eyes are antireflective because of naturally covered tapered nanostructures where the refractive index gradually increases as light travels to the moth's cornea," said Tolga Aytug.

"Combined, these features provide truly game-changing ability to design coatings for specific properties and performance. To be superhydrophobic, a surface must achieve a water droplet contact angle exceeding 150°. ORNL's coating has a contact angle of between 155 and 165°, so water literally bounces off, carrying away dust and dirt. This property, combined with the suppression of light reflection from a glass surface, is critical for improved performance in numerous optical applications," Aytug said.

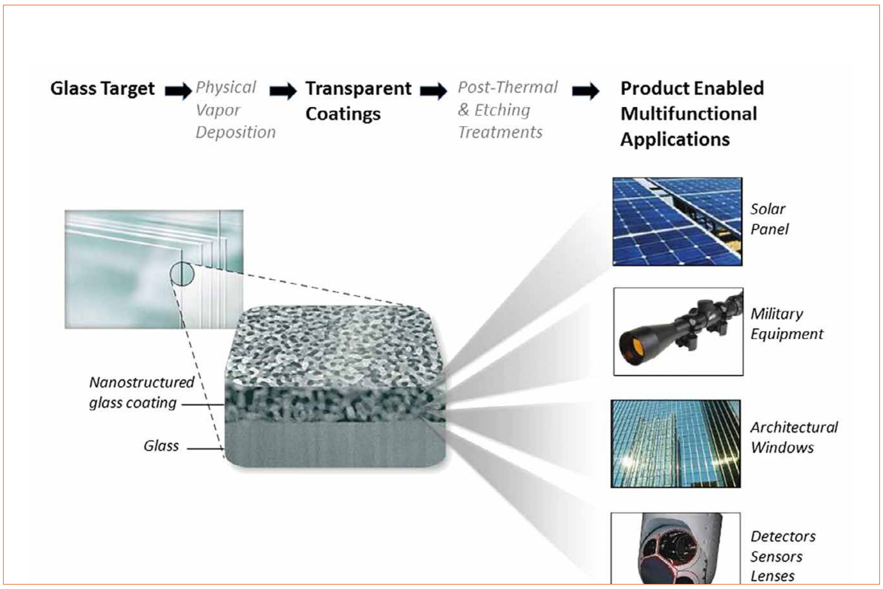
The base material - a special type of glass coating - is also highly durable, which sets it apart from competing technologies, according to Aytug, who described the process.

"We developed a method that starts with depositing a thin layer of glass material on a glass surface followed by thermal processing and selective material removal by etching," he said. "This produces a surface consisting of a porous three-dimensional network of high-silica content glass that resembles microscopic coral."

The fact the coating can be fabricated through industry standard techniques makes it easy and inexpensive to scale up and apply to a wide variety of glass platforms.

"The unique three-dimensionality interconnected nanoporous nature of our coatings significantly suppresses Fresnel light reflections from glass surfaces, providing enhanced transmission over a wide range of wavelengths and angles," said Aytug, lead author of the paper and a member of ORNL's Materials Chemistry Group. The Fresnel effect describes the amount of light that is reflected versus the amount transmitted.

Where solar panels are concerned, the suppression of reflected light translates into a 3-6 percent relative



Schematic representation of the coated product and applications. The properties could also be useful in different lighting applications like outdoor lighting, street lighting or automobile headlights

increase in light-to-electricity conversion efficiency and power output of the cells. Coupled with the superhydrophobic self-cleaning ability, this could also substantially reduce maintenance and operating costs of solar panels. In addition, the coating is highly effective at blocking ultraviolet light.

Other potential applications include goggles, periscopes, optical instruments, photodetectors and sensors. In addition, the superhydrophobic property can be effective at preventing ice and snow buildup on optical elements and can impede biofouling in marine applications.

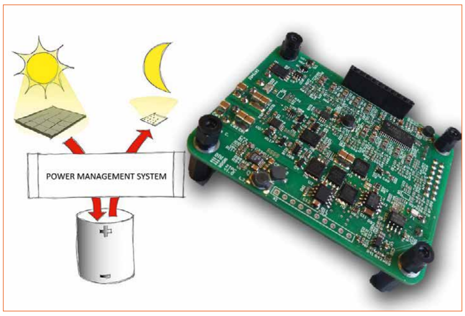
“This quality differentiates it from traditional polymeric and powder-based counterparts, which are generally mechanically fragile,” Aytug said. “We have shown that our nanostructure glass coatings exhibit superior mechanical resistance to impact abrasion – like sand storms – and are thermally stable to temperatures approaching 500°C.”

Other ORNL authors of the paper, titled “Monolithic Graded-Refractive-Index Glass-based Antireflective Coatings: Broadband/Omnidirectional Light Harvesting and Self-Cleaning Characteristics,” were A. Lupini, G. Jellison, P. Joshi, I. Ivanov, T. Liu, P. Wang, R. Menon, R. Trejo, E. Lara-Curzio, S. Hunter, J. Simpson, P. Paranthaman and D.Christen.

The work was supported by the Laboratory Directed Technology Innovation Program. STEM research was supported by the DOE Office of Science Basic Energy Sciences. A portion of the research was conducted at the Center for Nanophase Materials Sciences, a DOE Office of Science User Facility. Photovoltaic device measurements were done at the University of Utah.

Power Conversion Efficiency - Key for Stand-Alone Solar Powered Lighting

Stand-alone solar powered lighting solutions are made possible even in the Nordic region through a new, ground-breaking Danish project. An ideal collaboration between scientists from 4 different fields and private companies has succeeded in creating a system and a methodology that makes the impossible possible: Outdoor solar lighting which is not just a decoration.



A sophisticated driver design and controls system is the most relevant component for a truly efficient power conversion enabling the use of stand-alone solar powered lights in the Nordic regions even in winter time

At first glance, the best approach to make a solar powered outdoor lighting product work at winter in the far North is to go for state-of-the-art components: Photovoltaic panels, batteries and super effective LEDs. However, the heart of the systems is actually what binds these components together: The power supply and the battery management system.

With a very limited amount of PV power input during the short winter days, the energy conversion efficiency and the stand-by power consumption of the management system are crucial factors. In this project, a prototype channeled the power generated in the PV panel to the battery with an extreme efficiency of 98-99%. Most commercial LED power supplies consume 8-15% of the load. Nevertheless, the same prototype discharged a 10-25 W output from the battery to the LED with an impressive conversion efficiency of 97.5%.

A 10 W version was prototyped as well. In this case, high efficiencies are even harder to obtain, but even this model produced similar impressive conversion efficiencies.

The results have great potential in actual solutions that are ready for the market. Both prototypes were specified in close cooperation with private companies to enable direct use in real products. Hence, the prototypes were tested in five different outdoor products with LED.

And who says it will stop here? The project generated an advanced design and dimensioning tool that can manage all of the limiting conditions. All parts are highly dependent on temperature conditions in the environment and the PV panels obviously depend on latitude and shading conditions. Hence, all local conditions as well as the dynamical and technical performance figures of potential components can be loaded into the design tool, and an optimized solution can be designed.

This design tool is valuable not only in stand-alone solar systems in the Nordic region but essentially all over the world. Furthermore, the prototyped power managements system can be applied to many other PV-systems, as for instance stand-alone outdoor surveillance and intelligent parking meters.

EYESTvzw is a Belgium based non-profit organization established in November 2011 by members of the Brussels Photonics Team of the Vrije Universiteit Brussel. The sole mission of EYESTvzw is raising the interest of youths in engineering, science and technology through creation and dissemination of educational programs, mainly to schools.

PHOTONICS EXPLORER - ENGAGE, EXCITE, EDUCATE MORE THAN 100,000 STUDENTS IN IYL2015

by Tine De Pauw, Eyest

The Photonics Explorer is an intra-curricular educational kit designed to engage, excite and educate students about the fascination of working hands-on with light and optics in the classroom. The kit was developed within an EU project. Since November 2011, EYESTvzw was responsible for the assembly and mass distribution and for supporting teachers in their endeavour to convey the fascination of science and engineering to pupils. The aim is to inspire the next generation of scientists and engineers by distributing more than 1,500 Photonics Explorer kits.

The development of EYEST's educational programs is financially supported by sponsoring companies and governments and made available to teachers, students and schools. EYESTvzw is currently responsible for the fundraising for and the assembly of the Photonics Explorer kit as well as for its distribution throughout Europe.

To let students experience the excitement of doing science with their own hands, they need robust, versatile and safe experimental equipment. Therefore, each Photonics Explorer kit contains a class set of different components for hands-on experiments. Mirrors, colour filters, LED modules, lenses, polarisers, lasers, diffraction gratings, foils with double slit and an optical fibre are included in the kit.

In addition to these components, the didactic framework includes 8 educational modules with worksheets, factsheets, and notes for teachers. Some modules also feature videos, which are specially produced to support the suggested lesson outlines.

To organize the distribution all over Europe, EYESTvzw works together with very motivated partners in several European countries. Local Associated Partners are responsible for teacher training and distribution of the Photonics Explorer in a particular country or region. In the framework of the European project LIGHT2015, EYESTvzw had the opportunity to introduce the use of the Photonics Explorer as an educational tool in a number of countries where it was not already represented. 10 new local associated partners received training with practical information about the kit and its content and best practices on how to organize a training session for teachers. Soon these trained local associated partners will transfer their acquired skills to teachers and start distributing photonics explorer kits in their regions.

Together with its Local Associated Partners, EYESTvzw aims to distribute at least 2,015 Photonics Explorer kits in IYL2015, to engage, excite and educate at least 100,000 students every year! ■

T.D.P.

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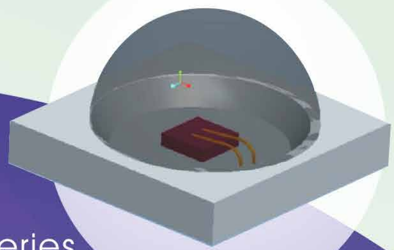
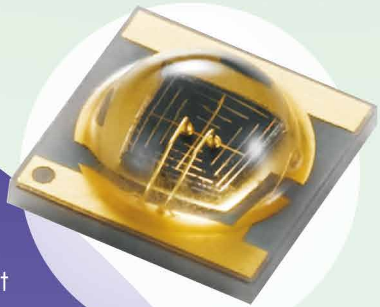


RE35 series



RC35 series

- Outstanding product performance：higher light intensity、better light intensity maintenance、lower thermal resistance
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- Complete product specifications :Half intensity angle±60°、±45°、±30°、±15°

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Exclusive Interview: Nobel Prize and Global Energy Prize Winner Prof. Shuji Nakamura

On June 19th, 2015 Nobel and Millennium prize winner, Professor Shuji Nakamura was awarded the Global Energy Prize in St. Petersburg, Russia. The Global Energy Prize is given to researchers in the field of energy efficiency and renewable technologies on a global scale. During the Global Energy Prize Event in St. Petersburg, Professor Nakamura gave an exclusive interview about the developments and future of solid-state lighting. Siegfried Luger, CEO of Luger Research, Event Director of the LpS 2015 and Publisher of LED professional, talked with Professor Nakamura about LED substrate technologies, violet and ultra-violet emitters, nano-technologies, OLEDs and laser technologies.

LED professional: It's a great pleasure and honor to have this opportunity to talk with you about solid-state lighting here in St. Petersburg on the occasion of the Global Energy Prize event. If you don't mind, I would like to start with a question related to LED substrate technologies. After your invention of the blue and white LEDs, you started doing research on GaN-on-GaN technology at the University of California Santa Barbara (USCB). When was this exactly?

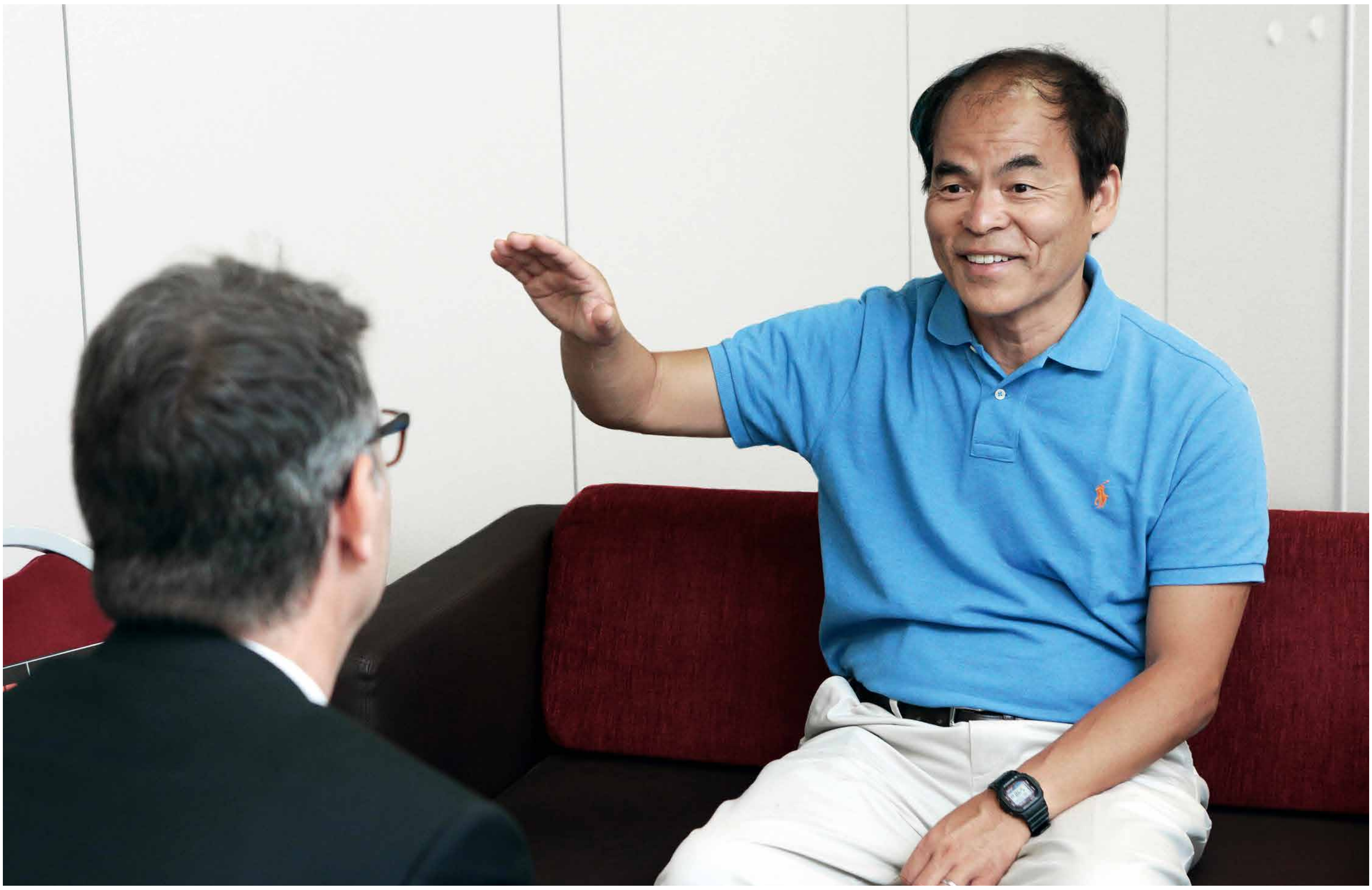
Professor Nakamura: I moved to USCB as a professor in the Material Department in the year 2000. And that's when we started to do research on GaN-on-GaN technology. At that time, nobody did work on GaN-on-GaN.

LED professional: What are the major advantages of GaN-on-GaN technology in comparison to other basic LED substrate technologies?

Professor Nakamura: Basically, the dislocation effects are much lower with GaN-on-GaN technology because the substrate is the same material as the epitaxial growth material. The lattice mismatch for GaN-on-Sapphire technology is much higher because the atomic arrangement is different. On the interface between Sapphire and GaN there are a huge number of dislocations with a density of approximately 10^9 cm^{-2}. These dislocations basically cause non-radiation effects because the electrons in the InGaN layer are captured in the dislocations instead of recombining and the emission gets low especially at high current densities. On the other hand, with GaN-on-GaN technology the recombination works efficiently due to minimized dislocations and, in addition, thermal stress is also minimized.

LED professional: Does this lead to higher efficacy values when using GaN-on-GaN substrate technology instead of GaN-on-Sapphire technology, for example?

Professor Nakamura: Yes, this is especially the case at higher current densities because those undesirable recombinations caused by



Prof. Shuji Nakamura and Siegfried Luger met in St. Petersburg in advance of the Global Energy Prize award ceremony for an exclusive interview

Prof. Nakamura answered questions about LED-, OLED-, Laser- and Nano-technologies in a relaxed setting

crystal dislocations are very active at high current densities. We founded a company named Soraa in 2008, which is using GaN-on-GaN technology. Soraa started the commercialization of GaN-on-GaN technology, and, hence, GaN-on-GaN LEDs. These products use between 5 to 10 times higher current densities, with up to 1000 Acm^{-2}, as conventional LEDs on Sapphire based devices.

LED professional: But what about the droop effect with the GaN-on-GaN technology at such high current densities?

Professor Nakamura: The current droop effect is especially composed of Auger recombination with a contribution of about 50%. The other 50% comes from carrier overflow and dislocation. The droop effect with GaN-on-GaN is small because of the elimination of dislocations. With foreign substrate materials the droop effect is in the region of minus 18% to 27% while GaN-on-GaN technology shows just about minus 4%. Also with violet LEDs the droop effect is smaller than with blue LEDs.

LED professional: Another substrate technology is GaN-on-Silicon. How do you see this technology, which is also especially driven to reduce the future costs of the devices?

Professor Nakamura: GaN-on-Silicon dislocation is similar to GaN-on-Sapphire and the thermal mismatch is very high. The process of manufacturing GaN-on-Silicon LEDs is very complicated because it is necessary to insert additional layers to minimize the stress effects and the yield is very poor.

LED professional: To conclude the discussion about the substrate material: Which material will be the winner at the end of the developments?

Professor Nakamura: GaN-on-GaN technology will be the winner in the future. Just think of same size chips. The GaN-on-GaN chip would be five times brighter than chips based on other technologies. This means for the same light output we could reduce the chip size of a GaN-on-GaN based substrate chip to one-fifth of the size of a conventional LED chip because the current is five times higher. The substrate is expensive but for an LED bulb, for example, the substrate contributes with just about 10 to 13 % of the total costs.

LED professional: With such high current densities and brightness per single light point the glare problem might become much more important in applications. How do you see these visual effects and how can we solve these problems?

Professor Nakamura: For lighting designs you just need a point light source because then it is easy to control the light by just using a lens. With a lens you can do any kind of light distribution. To use a single lens approach we need a very tiny chip, which is the case with the GaN-on-GaN technology. A point light source based on a tiny chip is the principal used to help reduce the system costs because elements such as optics and cooling devices can be minimized.

LED professional: Are there any bottlenecks for mass production for the GaN-on-GaN technology when considering high-volume manufacturing?

Professor Nakamura: Right now GaN substrate is growing by hydride vapor-phase epitaxial (HVPE) growth, which is an expensive production process. We do research to reduce the cost of GaN substrate production further. So right now, we are doing research with

For the Celebration Issue 50, Prof. Nakamura and Siegfried Luger discussed the future of Solid-State Lighting from substrates to applications

ammono-thermal GaN crystal growth methods, which will be ready for mass-production for 4-, 6- and 8-inch GaN wafers in about 3 to 5 years. The research team is also testing growing GaN on different crystal planes to create semi-polar LEDs to drive down costs.

LED professional: You did a lot of research with different wavelengths as a primary source from the blue to violet up to ultra-violet bandwidths. What is the best choice for generating white light systems?

Professor Nakamura: UV LEDs were not planned to use for lighting. UV LEDs are for instance used in water purification or curing applications. Overall, the violet bandwidth is the best choice when you take the Stoke's shift losses, color rendering and the excitation of materials like fluorescents into account. For example, blue LEDs have wall-plug efficiencies between 50 and 60% but with the violet GaN-on-GaN technology the wall-plug efficiency is about 80%, which is world record. But taking the Stoke's shift into account for the shorter wavelength of the violet, then both systems are similar in efficiency but the difference is for the CRI value. Emitting in the violet bandwidth the CRI is more than 95 where in comparison the blue LEDs are typically at 85 CRI. With violet systems, having a full-spectra light, we can almost copy sunlight.

LED professional: Let's talk about the laser technology for generating white light, which is currently used as a high beam booster in headlamps for the high-class cars, Audi R8 and BMWi8. Is this also a technology for general lighting applications in the future?

Professor Nakamura: The first generation to produce white light was the blue LED technology. The second generation of white light sources is the violet GaN-on-GaN technology and the third generation is laser technology. For blue LEDs the current densities are just around 10 Acm^{-2} with a huge droop effect. For violet LEDs we reach about 50-100 Acm^{-2} but the laser diode uses 3-10 $kAcm^{-2}$ which is about 1,000 times higher than blue LEDs. This leads to very tiny chips in combination with the same phosphors such as YAG types. The light output is about 1,000 times higher than conventional LEDs with the same chip-size.

LED professional: So, are you saying that laser technology is the third generation and that in maybe a decade, this technology will replace all other ones for generating white light?

Professor Nakamura: Yes, in about 10 years all white light systems will become laser-based lighting and the blue LEDs will be replaced completely. Think of a reduction in chip-size by a factor of 1,000. In terms of thermal management it will be easy because the chip-size is very small. Also, we can reach up to 90% of wall plug efficiencies with laser-diodes in the future. This technology will be ready in 5 to 10 years because we see existing applications in the automotive industry right now. By then it will also be used for general lighting. Just think of this meeting room here: One tiny chip based on laser technology will be enough to illuminate the whole room. It's easy to distribute the light based on a very tiny point light source. We could not reach this with blue LEDs.

LED professional: What type of research are you doing in laser technology right now?

Prof. Shuji Nakamura

Shuji Nakamura was born on May 22, 1954, in Ehime, Japan. He received his B.E., M.S., and Ph.D. degrees in electrical engineering from the University of Tokushima, Tokushima, Japan, in 1977, 1979, and 1994, respectively. He joined Nichia Chemical Industries Ltd., Tokushima, Japan, in 1979. In 1988, he spent a year at the University of Florida, Gainesville, FL, USA, as a Visiting Research Associate. In 1989, he started the research of blue LEDs using group-III nitride materials. In 1993 and 1995, he developed the first group-III nitride-based blue/green LEDs. He also developed the first group-III nitride-based violet laser diodes (LDs) in 1995. Since 2000, he has been a Professor at the Materials Department, University of California Santa Barbara, Santa Barbara, CA, USA. He holds more than 300 patents and has published more than 400 papers.

Dr. Nakamura has received a number of awards, including: The Nishina Memorial Award (1996), the MRS Medal Award (1997), the IEEE Jack A. Morton Award, the British Rank Prize (1998), and the Benjamin Franklin Medal Award (2002). He was elected a member of the U.S. National Academy of Engineering (NAE) in 2003. He received the Finnish Millennium Technology Prize in 2006. In 2008, he also received the prize of Asturias Award from Spain. He received the Harvey Prize of the Israel Institute of Technology in 2010. The 2014 Nobel Prize for physics has been awarded to a trio of scientists (Professors Isamu Akasaki, Hiroshi Amano and Shuji Nakamura) in Japan and the US for the invention of blue light emitting diodes. In June 2015 Professor Nakamura received the Global Energy Prize in St. Petersburg for the invention, commercialization and development of energy-efficient white lighting technology together with Jayant Baglia for the invention, development and commercialization of Insulated Gate Bipolar Transistor, which is one of the most important innovations for the control and distribution of energy.

Professor Nakamura: In 2008 we founded two companies. One is Soraa, which focuses on LED lighting especially the GaN-on-GaN violet LEDs. Kaai focused on laser technology for lighting applications. After a merging of these companies we split them again and the laser part is now called Soraa Laser Diode. The development of laser lighting takes time for two reasons: The wall-plug efficiency is at 30% at the moment, so about half of the blue LED values. We have to increase that to reach more than 50, 60 or even 70%. The other problem is the costs because the laser diodes are expensive. They are about 10 times more than conventional LEDs. To overcome this we have to increase the yield and find solutions for any kind of process problems. However, we are very optimistic that we can solve these problems for this new technology.

LED professional: So that is a clear view on the future development steps for white light generation from blue LEDs to violet LEDs and finally to Laser lighting. But how do you see the developments in Nano-technologies?

Professor Nakamura: I saw results of red and green laser diodes with Nano-wired technologies. It is a great technology. I like the phosphor concept to make white light because we need broad spectra, like sunlight. With specific Nano-spectra we are missing colors and therefore, for me, phosphor is the best concept to generate white light and it can be used for all white light technologies. The human friendliest light is sunlight. It is the best for the human eye and so we have to copy sunlight to reach a full spectra and to prevent missing colors.

LED professional: Another technology, which has been developed over the last years are OLEDs. Do you see OLEDs for general lighting applications as an alternative technology to your shown three generations SSL roadmap?

Professor Nakamura: For lighting applications I don't see a way with OLEDs. I think it is too late because with existing LEDs you also can produce flexible lighting systems. The advantage of OLEDs is that they can be very thin for flat designs. But we also can make the same type of designs with LED lighting. And OLED lighting still has problems with reliability and costs.

LED professional: What are the TOP-three research fields, or let us say challenges, for white light system developments?

Professor Nakamura: On a chip level we have the current droop problem to solve, so droop is the biggest issue. For laser lighting we have no droop issues, so for me laser lighting is the perfect light source. On a chip level we can solve any kind of problems, I think. On a system level the biggest issue is the heat sink and heat temperature increase. Also the laser lighting phosphor is a big challenge because the light output density is so high that with the same designs as for blue LEDs the phosphor would be burned down. For this reason they use a special remote ceramic phosphor in automotive applications.

LED professional: Professor Nakamura your research and inventions have a big influence on many areas in our lives and your contributions to environmental issues are so big. The Nobel Prize and now the Global Energy Prize both confirm these contributions. How do you feel and what do you think when looking back at your research and your findings?

Professor Nakamura: Of course I'm very happy. But the Nobel Prize and the Global Energy Prize was given for the invention of the blue LEDs. But the second and third generation of lighting is required to improve lighting further. So in fact I'm happy, but it's not good enough! ■

LpS 2015 - PROGRAM

EVENT OVERVIEW

DAY 1

SEPT. 22ND
TUESDAY

Opening

10.00 - 10.30	**Opening & Scientific Award Ceremony** | Grosser Saal
10.30 - 12.00	**Keynotes** | Grosser Saal

Parallel Sessions

13.30 - 18.00	**Light Quality** | Seestudio
13.30 - 15.30	**Connectivity & Security** | Seefoyer
16.30 - 18.00	**Reliability & Lifetime** | Seefoyer
13.30 - 15.30	**Standardization** | Propter Homines
16.30 - 18.00	**Workshop Light Measurement** *by GL Optics* | Propter Homines
10.00 - 20.00	**Design meets Technology Day** | Grosser Saal, Foyer & Expo

Evening Events

18.00 - 20.00	**Poster Session** | Foyer
18.00 - 20.00	**Exhibition Reception & Oktoberfest** | Werktstattbühne & Seitenbühnen

DAY 2

SEPT. 23RD
WEDNESDAY

Parallel Sessions

08.30 - 15.30	**Light Sources** | Seestudio
08.30 - 15.30	**Smart Controls & Drivers** | Seefoyer
08.30 - 12.30	**Thermal Management** | Propter Homines
13.30 - 15.30	**Optics** | Propter Homines
16.30 - 18.00	**Workshop OLEDs** *by LG Chem* | Saal Bodensee
16.30 - 18.00	**Workshop Optics** *by Lambda Research* | Saal Bodensee
16.30 - 18.00	**Workshop Thermal Management** *by ams* | Propter Homines

Evening Events

17.00 - 18.00	**Press Conference** | Parkstudio
18.30 - 23.00	**Get-Together Event** | Boat Trip on Lake Constance

DAY 3

SEPT. 24TH
THURSDAY

Parallel Sessions

09.00 - 10.30	**Lighting Systems** | Seestudio
09.00 - 10.30	**Optics** | Propter Homines
09.00 - 12.30	**Measurement and Production** | Seefoyer
11.30 - 12.30	**Workshop Smart Controls** *by Luger Research* | Propter Homines
11.30 - 12.30	**Workshop Light Mixing** *by LightCube/Uni Padua* | Seestudio
09.00 - 12.30	**Workshop Automotive Lighting** *by EPIC* | Saal Bodensee

Plenum Sessions

13.30 - 14.30	**Tech-Panel: Key Trends & Technologies** | Seestudio
14.30	**Closing** | Seestudio

DAY 1 - SEPTEMBER 22ND - TUESDAY

Time	Opening, Keynotes & Light Quality	Connectivity, Security, Reliability & Lifetime	Standardization & Light Measurement	Design meets Technology Day
10.00	Grosser Saal **Opening & Scientific Award Ceremony**			DMT Day | Grosser Saal **Opening**
10.30	KEYNOTE | Grosser Saal **Semantic Light** *Prof. Zary Segall, Royal Institute of Technology, Sweden*			DMT Day | Grosser Saal **Keynote**
11.00	KEYNOTE | Grosser Saal **The Second Wave of Lighting Innovation - Towards Lighting Beyond Illumination** *Rogier van der Heide, Chief Design & Marketing Officier at Zumtobel Group, Austria*			DMT Day | Grosser Saal **Keynote**
11.30	KEYNOTE | Grosser Saal **Trends and Challenges for System Integration** *Dr. Jy Bhardwaj, CTO at Lumileds, USA*			DMT Day | Grosser Saal **Keynote**
BREAK				
13.30	LIGHT QUALITY | Seestudio **Human Centric Lighting - What We Know and What is Needed** *DI Peter Dehoff, Zumtobel Group & LightingEurope, Austria, The Netherlands*	CONNECTIVITY & SECURITY | Seefoyer **Why We Need Smarter Smart Lighting** *Dr. Walter Werner, CEO at Werner Mgt. Consulting, Austria*	STANDARDIZATION | Propter Homines **OpenAIS - Innovation Towards an Open Architecture for Intelligent Solid-State Lighting** *Dr. Christian Moormann, Head of Global Technology, Tridonic, Austria*	DMT Day | Foyer, Expo **Exhibition Walkthrough**
14.00	LIGHT QUALITY | Seestudio **CIE Test Method for LED Lamps, LED Luminaires and LED Modules** *Dr. Peter Blattner, Head of Optics Laboratory at METAS, Switzerland*	CONNECTIVITY & SECURITY | Seefoyer **Lighting Systems and Cyber Security** *Ken Modeste, Principal Engineer at Underwriter Laboratories (UL), USA*	STANDARDIZATION | Propter Homines **Zhaga Standardization of LED Light Engines, Modules and Drivers Helps to Simplify LED Luminaire Design** *Musa Unmehopa, Secretary General at Zhaga Consortium, The Netherlands*	DMT Day | Foyer, Expo **Exhibition Walkthrough**
14.30	LIGHT QUALITY | Seestudio **Concepts of Intelligent Lighting and LED Luminaires Taking Color Quality and Human Centric Lighting into Account** *Prof. Tran Quoc Khanh, TU Darmstadt, Germany*	CONNECTIVITY & SECURITY | Seefoyer **Intelligent Methods to Secure Connected Lighting and Smart City Installations** *Dr. Geoff Archenhold, Serenity Lighting, UK*	STANDARDIZATION | Propter Homines **An Introduction to DALI 2** *Steve Roberts, CTO at Recom, Austria*	DMT Day | Foyer, Expo **Exhibition Walkthrough**
15.00	LIGHT QUALITY | Seestudio **The Degrees of Freedom Provided by Modern Methods to Tune CCT and LED Wavelengths** *Wojtek Cieplik, LEDengin*		STANDARDIZATION | Propter Homines **Challenges and Solutions of Photobio-logical Safety Assessment for Lighting Products** *Prof. Jiangen Pan, CEO at Everfine, China*	DMT Day | Foyer, Expo **Exhibition Walkthrough**
BREAK				
16.30	LIGHT QUALITY | Seestudio **Quality of LED Lamps for Residential in European Market and Associated Health Issues** *Prof. Georges Zissis, Toulouse 3 University, France*	RELIABILITY & LIFETIME | Seefoyer **Reliability of High Power LEDs: From Gradual to Catastrophic Failure** *Prof. Matteo Meneghini, University of Padua, Italy*	Propter Homines **WORKSHOP LIGHT MEASUREMENT** *by GL Optic, Germany*	DMT Day | Expo **Luminary Design Prize**
17.00	LIGHT QUALITY | Seestudio **SSL Solutions for Human Centric Lighting** *Dr. Nicola Trivellin, LightCube, Italy*	RELIABILITY & LIFETIME | Seefoyer **LED Tunnel Lamp - A Reality Check: 50,000 Hours Field Data and Lifetime** *Alexander Wilm, SSL Expert, OSRAM Opto Semicon-ductors, Germany*	Propter Homines **WORKSHOP LIGHT MEASUREMENT** *by GL Optic, Germany*	DMT Day | Expo **Exhibition**
17.30	LIGHT QUALITY | Seestudio **Sky Luminance and Radiance Distribu-tion Patterns: Empirical Assessment and Computational Models** *Prof. Ardeshir Mahdavi, Technical University Vienna, Austria*	RELIABILITY & LIFETIME | Seefoyer **Statistical Analysis and Prediction of LED Lifetimes** *Dr. Wolfgang Scheuerpflug, Diehl Aerospace, Germany*	Propter Homines **WORKSHOP LIGHT MEASUREMENT** *by GL Optic, Germany*	DMT Day | Expo **Exhibition**
18.00 | 20.00	Werkstattbühne & Seitenbühnen **OKTOBERFEST**	Foyer **POSTER SESSION**	Werkstattbühne & Seitenbühnen **EXHIBITION RECEPTION**	DMT Day | Expo **Networking**

DAY 2 - SEPTEMBER 23RD - WEDNESDAY

Time	LED & OLED Light Sources	Smart Controls, Drivers & Optics	Thermal Management & Optics
08.30	LIGHT SOURCES | Seestudio **Solid-State Light Products Design Breakthrough** *Mauro Ceresa, Field Application Engineer, Cree, Italy*	SMART CONTROLS & DRIVERS | Seefoyer **Energy and Light Quality Results of EnLight Lighting Solutions Applied to a Hospitality Environment** *Dr. Herbert Weiß, Project Manager Corp. Technology at OSRAM, Germany*	THERMAL MANAGEMENT | Propter Homines **The Effect of Dynamic Thermal Management for Smart Controlled Solid State Lighting Systems** *Dr. Mehmet Arik, Ozyegin University, Turkey*
09.00	LIGHT SOURCES | Seestudio **Progress in Single Crystal Luminophores for High Power LEDs and LDs** *Dr. Jan Kubat, Head of Materials and Precision Optics at Crytur, Czech Republic*	SMART CONTROLS & DRIVERS | Seefoyer **Human-Focused Outdoor Illumination: A Trade-off Between Pleasing Color and Circadian Action** *Dr. Prancisskus Vitta, Vilnius University, Lituanica*	THERMAL MANAGEMENT | Propter Homines **A Case Study: Opto-Thermal Modelling of a Mid-Power LED** *Dr. V.D. Hildenbrand, Researcher at Philips Lighting Solutions, The Netherlands*
09.30	LIGHT SOURCES | Seestudio **An Iterative Optical and Thermal Simulation Method for Proper Simulations of Phosphor Converted LEDs** *Dr. Wolfgang Nemitz, Researcher at Joanneum Research, Austria*	SMART CONTROLS & DRIVERS | Seefoyer **A New Software Approach/Architecture for Scalable Distributed Lighting Control** *Prof. Peter Niebert, CTO LED's CHAT, France*	THERMAL MANAGEMENT | Propter Homines **Reliability of Interconnects in LED Lighting Assemblies Utilizing Metal Clad Printed Circuit Boards** *Justin Kolbe, Principal Engineer at The Bergquist Company, USA*
BREAK			
11.00	LIGHT SOURCES | Seestudio **LED Lighting for Visual Merchandising** *Dr. Daniel Doxsee, Deputy Managing Director of Nichia Europe, Germany*	SMART CONTROLS & DRIVERS | Seefoyer **Wireless Mesh Networks Demystification** *Vladimir Sulc, CEO at MICRORISC, Czech Republic*	THERMAL MANAGEMENT | Propter Homines **Thermal Impedance Analysis of LED Modules** *Stefan Defregger, Material Center Leoben, Austria*
11.30	LIGHT SOURCES | Seestudio **Trends in SMD LED Packages for General Lighting** *Dr. Christopher Keusch, Everlight Electronics, Germany*	SMART CONTROLS & DRIVERS | Seefoyer **Quality Characteristics of LED Power Supplies and Drivers** *DI Stephan Wegstein, CEO at sysLED, Germany*	THERMAL MANAGEMENT | Propter Homines **Nanoceramic Substrates for Thermal Management of High Brightness LEDs** *Dr. Giles Humpston, FAE at Cambridge Nanotherm, UK*
12.00	LIGHT SOURCES | Seestudio **Leveraging Chip Scale Package Technology to Deliver a Robust and Future-Proof Platform** *Ingolf Sischka, Technical Solution Manager at Lumileds, Germany*	SMART CONTROLS & DRIVERS | Seefoyer **Reliable and Cost Effective LED Drivers Improving Perception Artefacts and Grid Compatibility** *Prof. Eberhard Waffenschmidt, Cologne University, Germany*	THERMAL MANAGEMENT | Propter Homines **Advantages of Using Thermally Conductive Polymers for Heat Sinks** *Dr. Klaus S. Reinartz, Marketing Manager at Bayer Material Science, Germany*
BREAK			
13.00	LIGHT SOURCES | Seestudio **Luminescent Glasses and Glass Ceramics for White Light Emitting Diodes** *DI Franziska Steudel, Research at Fraunhofer, Germany*	SMART CONTROLS & DRIVERS | Seefoyer **Advantages and Challenges of Modern Software Based Digital SMPS LED Drivers** *Mikael Pettersson, R&D Manager at SwitchTech, Sweden*	OPTICS | Propter Homines **Why Moldable Silicone is Driving Innovation in Engineering of LED Optics for Professional Lighting?** *Dr. Francois De Buyl, Dow Corning, Belgium*
14.00	LIGHT SOURCES | Seestudio **Spectrally Tuneable SSL Solutions and Applications** *Dr. Josep Carreras, Head of the Lighting Group at IREC, Spain*	SMART CONTROLS & DRIVERS | Seefoyer **How to Combine Smart Lighting with a Driverless, AC-Driven Solution** *Lorenz Bauer, Field Application Engineer at Seoul Semiconductor, Germany*	OPTICS | Propter Homines **Sensitivity of the Optical Performance of LED Illumination Systems to Manufacturing Tolerances** *Dr. Christian Paßlick, Engineer at Auer Lighting, Germany*
14.30	LIGHT SOURCES | Seestudio **Human Centric Lighting: The Future of the Lighting Industry** *Prof. Guenther Leising, Lumitech, Austria*	SMART CONTROLS & DRIVERS | Seefoyer **PFC Flyback with Software Controlled Digital Driver** *Ulrich vom Bauer, Infineon, Germany*	OPTICS | Propter Homines **Styrenics for LED lighting – How Specialty Styrenics Open New Possibilities in LED Lighting** *Dr. Eike Jahnke, Technical Product Manager at Styrolution, Germany*
15.00	LIGHT SOURCES | Seestudio **What is the Future of OLED for Lighting?** *Pars Mukish, Analyst at Yole Developpement, France*		OPTICS | Propter Homines **Thin-Film Light Management System for Intelligent Large-Area LED Luminaires** *Dr. Oscar Fernandez, CSEM, Switzerland*
BREAK			
16.30 – 18.00	Saal Bodensee **WORKSHOP** **OLEDs** *by LG Chem, Korea*	Saal Bodensee **WORKSHOP** **OPTICS** *by Lambda Research, USA*	Propter Homines **WORKSHOP** **THERMAL MANAGEMENT** *by ams, Germany*
17.30	Parkstudio **PRESS-CONFERENCE**		
18.30 – 23.00	Boat trip on Lake Constance **GET TOGETHER EVENING**		

DAY 3 - SEPTEMBER 24TH - THURSDAY

Time	Lighting Systems, Light Mixing & Tech-Panel	Measurement & Production	Optics & Smart Controls	Automotive Lighting
09.00	LIGHTING SYSTEMS | Seestudio **The Paradigm Shift of Residential Lighting from Retrofit Lamps to Fully Integrated Fixtures** *Jeremy Ludyjan, Director of Innovation at Bulbrite Industries, USA*	MEASUREMENT & PRODUCTION | Seefoyer **New Standards for the Photometry of LED Based Light Sources – A Challenge for the Laboratories** *Dr. Udo Krüger, Head of Photometry, TechnoTeam, Germany*	OPTICS | Propter Homines **Better Light Through Optical Design for Manufacturing** *Dr. Angelika Hofmann, Optical Design Manager at kdg Opticomp, Austria*	Saal Bodensee **WORKSHOP AUTOMOTIVE LIGHTING** *by EPIC*
09.30	LIGHTING SYSTEMS | Seestudio **Six-Channel LED-Luminaire for Retail Lighting** *Prof. Meike Barfuss, FH Suedwestfalen, Germany*	MEASUREMENT & PRODUCTION | Seefoyer **How to Guarantee 1-Step MacAdam Ellipse Color Bins for LEDs in General Lighting** *Dr. Matthias Hoeh, Product Manager at Instrument Systems, Germany*	OPTICS | Propter Homines **Diffusion Panels - The Way Out of the Glaring Inhomogeneous LED Misery** *Dr. Dieker Henning, R&D Designer at VS Lighting, Germany*	Saal Bodensee **WORKSHOP AUTOMOTIVE LIGHTING** *by EPIC*
10.00	LIGHTING SYSTEMS | Seestudio **High-Temperature Reliability of Retrofit LED Bulbs** *Dr. Matteo Dal Lago, Researcher at LightCube, Italy*		OPTICS | Propter Homines **24/7 Custom Optics: Improved Capabilities Increase Manufacturing Speed and Flexibility Significantly** *Bram Meulblok, LUXeXceL, The Netherlands*	Saal Bodensee **WORKSHOP AUTOMOTIVE LIGHTING** *by EPIC*
BREAK				
11.30	Seestudio **WORKSHOP LIGHT MIXING** *by LightCube & University of Padua, Italy*	MEASUREMENT & PRODUCTION | Seefoyer **Adhesive Developments for Low Cost Flip-Chip and High Precision Bonding in LED Lighting Applications** *Andreas Kraft, Business Development Manager at DELO, Germany*	Propter Homines **WORKSHOP SMART CONTROLS** *by Luger Research, Austria*	Saal Bodensee **WORKSHOP AUTOMOTIVE LIGHTING** *by EPIC*
12.00	Seestudio **WORKSHOP LIGHT MIXING** *by LightCube & University of Padua, Italy*	MEASUREMENT & PRODUCTION | Seefoyer **New High Speed Assembly Technology "Reel to Reel Flip Chip LED"** *Franz Brandl, Head of R&D at Mühlbauer, Germany*	Propter Homines **WORKSHOP SMART CONTROLS** *by Luger Research, Austria*	Saal Bodensee **WORKSHOP AUTOMOTIVE LIGHTING** *by EPIC*
BREAK				
13.30 – 14.30	Seestudio **TECH PANEL** **KEY TRENDS & TECHNOLOGIES**			
14.30	**CLOSING**			

Flexible OLEDs for Lighting Applications

While OLEDs already have successfully found their way into display applications, the breakthrough in lighting applications is still pending. The reasons are diverse, but cost is one major point. Another reason is the current edge of inorganic LEDs giving reasonable design opportunities in many standard applications. However, there are applications where OLEDs could score, especially the flexible OLEDs. But even these OLEDs need to become cheaper to be applied widely. The Holst Centre and partners aim to develop generic technologies for large area flexible OLEDs which can be processed with roll-to-roll (R2R) technology. Process Engineer Tansim Baig gives an example and an overview of the current status of the development.

In collaboration with our industrial and academic partners, Holst Centre aims to develop generic technologies for large area flexible OLED lighting, including thin film water barriers, which can be processed with roll-to-roll (R2R) compatible technology with high yield. This presentation/ article will give an overview of the key technological developments that are required in order to realize such devices. Highlights from our work will be presented, including devices on plastic and metal foil substrates with solution processed multilayers deposited using our R2R line, large area transparent electrodes including printed metal grids, techniques for light extraction in flexible devices and state-of-the-art thin film flexible water barrier performance (black spot free flexible OLEDs after more than 2000 hours in 60°C/90%RH accelerated lifetime conditions). We will demonstrate flexible devices with comparable performance to glass-based commercially available devices.

Introduction

Organic Light Emitting Diodes (OLEDs) have gathered a lot of interest both from industry as well as academia since their discovery. Today, OLEDs are being used in displays of handheld mobile devices and for general lighting. Flexible, lightweight and with large area emissions in almost any shape, OLEDs will let us do more with light than ever before – opening up new designs and applications. And with lighting currently using around 20% of the world's electricity, OLEDs' potential for high efficiency could save huge amounts of energy and greenhouse gas emissions. Holst Centre, and its partners bring together expertise on technologies such as flexible barriers, and large area printing to realize ultrathin, flexible, large-area and moisture-resistant devices.

Barrier Foil by the Kilometer

Thin-film devices such as OLEDs and OPVs are very sensitive to moisture, so need a water barrier layer. Traditionally, glass/metal lids have been used to seal the OLEDs / OPVs on a rigid substrate and this resulted in higher lifetime but was expensive and difficult to scale up to large areas.
Then came the approach to thin film encapsulate the device which meant reduced costs, improved scalability to larger areas and most importantly lifetime comparable to glass

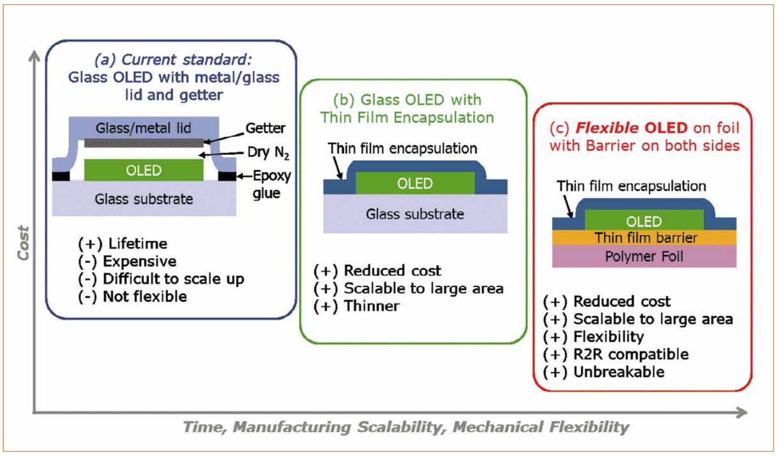


Figure 1:
Cost comparison for different encapsulation strategies with their advantages and disadvantages [1]

encapsulated devices. At the Holst Centre we are developing a low-cost, large-area thin film based barrier technology based on a SiN-organic-SiN stack which offers sufficient environmental protection to fulfill lifetime specifications of OLEDs / OPVs depending on the application. Most important is to keep in mind the scalability of the process for large area flexible lighting modules. The following diagram gives an overview of barrier encapsulation strategies vs cost.

Industry has widely adopted the multi-stack water barrier approach for encapsulation of flexible electronics but the main challenge has always been to avoid the pinhole-to-pinhole moisture diffusion. If the pinholes were coupled, that would create a faster channel for the moisture to seep into the device, thereby degrading the device and leading to the growth of black spots. The thin film, optically transparent water barrier developed at Holst Centre used in combination with metal cathode for top encapsulation of OLED devices on glass substrates has an overall water vapor transmission rate of 10-9 g/m²/day. This results in shelf lifetimes under accelerated shelf life conditions of 60°C/90% relative humidity of more than 4000 hours (approximately 10 years under normal conditions). For flexible OLEDs with a water barrier both above and below the device, shelf lifetimes under accelerated 60/90 conditions are already more than 2000 hours and research to improve this is underway. For flexible OPV devices, we have observed no drop in efficiency of the devices after testing for 7000 hours under 85/85 conditions, which should correspond to more than 60 years under normal conditions.
The following plots give more information about the performance of OLEDs and OPVs when tested under accelerated shelf life conditions of 60°C /90% relative humidity and 85°C/85% relative humidity respectively.

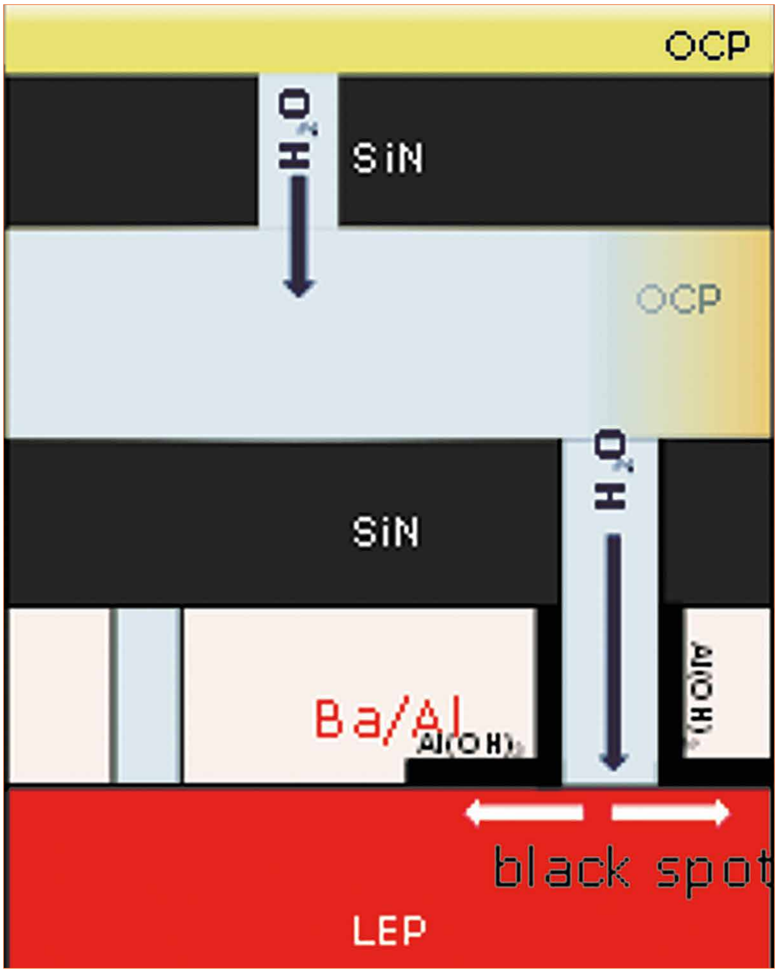


Figure 2:
Pinhole-pinhole coupling leading to black spot growth in the device [2]

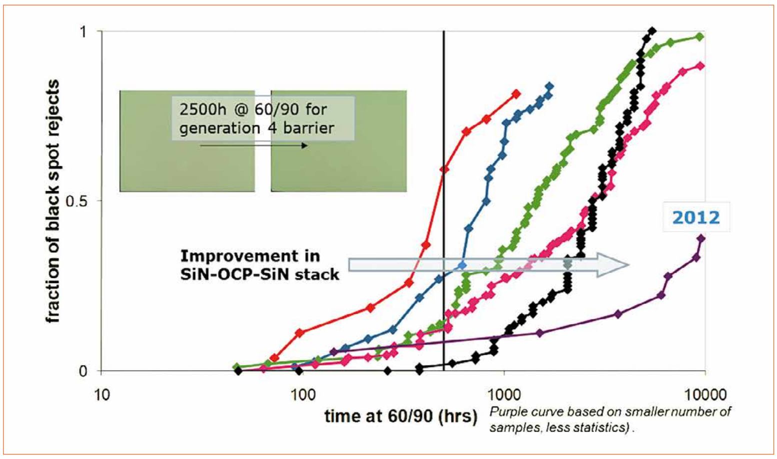


Figure 3:
Black spot growth rate in OLEDs with different generations of Holst Barrier technology [1]

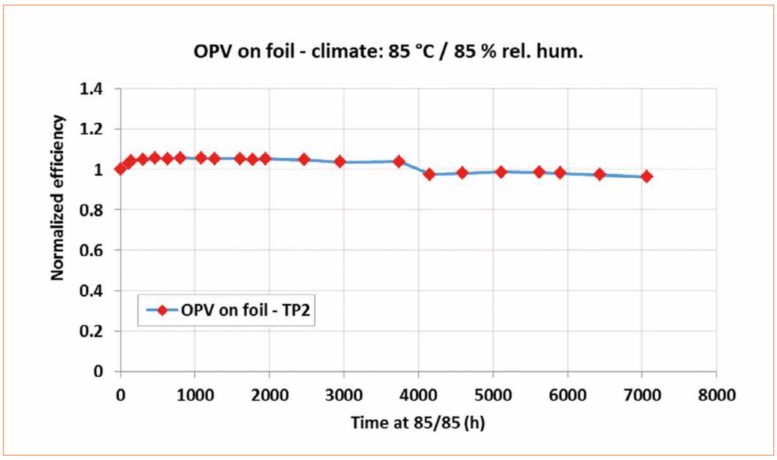


Figure 4:
Plot showing feasibility study for S2S processed Holst Centre barrier technology for OPVs [1]

Figure 5:
Flexible Lumiblade made in collaboration with Philips, Dupont Teijin Films, Rolic Technologies, Roth & Rau and Holst centre [2]

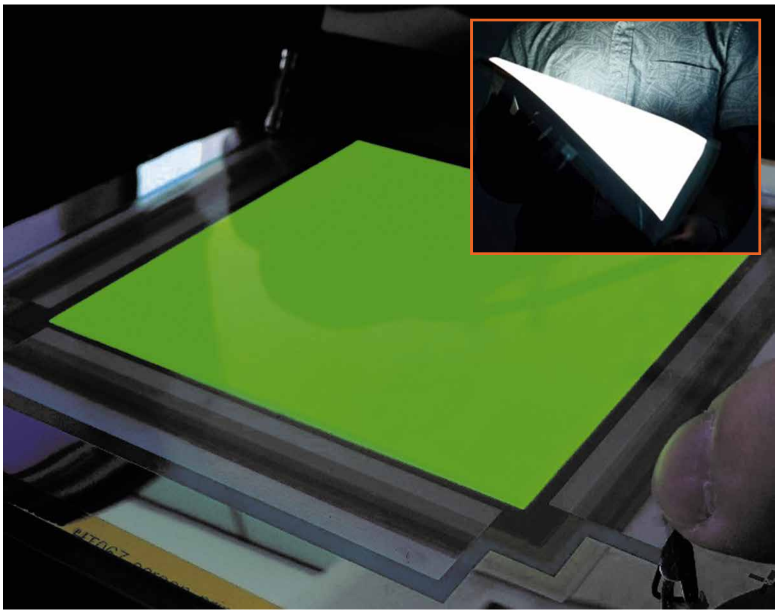


Figure 6:
R2R processed Top-emission OLED on Metal foil measuring 8 cm x 8 cm. Inset: R2R processed Bottom-emission OLED on Metal foil measuring 17 cm x 25 cm

For high-volume flexible applications, the barrier must also be flexible and mass-producible. Holst Centre and its industrial partners have developed a roll-to-roll system for barrier production. And in the last year (2013), the collaboration produced 1.4 km of a first generation of the barrier foil (just a single Silicon nitride layer), with an overall (including pinholes) water vapor transmission rate (WVTR) lower than 10-5 g/m^2 per day. This is already good enough for PV applications. To develop the roll-to-roll system, the team had to optimize a number of complex issues including web handling, particle contamination, layer homogeneities and the hardware itself. The next goals are to achieve even higher barrier performance by depositing the full barrier stack, increase yields and boost productivity, targeting 300 m of barrier foil per day in a truly industrial-scale process.

Flexible Lumiblade

Flexible OLED panels will enable stunning new lighting designs. In 2008, Philips took the first commercial steps in this direction with the launch of the Lumiblade OLED, a glass-based, non-dazzling light source sold as a component for integration into any design. Now, Philips and Holst Centre have developed a flexible version of the Lumiblade. With a 120 mm x 40 mm active area and thickness of just 0.2 mm, these demonstration devices deliver flawless white light at efficiencies of 47 lumens-per-Watt – comparable with glass-based Lumiblades. The flexible Lumiblade consists of a single polymer substrate with the small molecule evaporated OLED (processed in vacuum) sandwiched between two water barrier layers. The flexible Lumiblade device shows no signs of degradation after more than 2000 hours of accelerated lifetime testing at 60°C and 90% relative humidity. Work is ongoing to improve light outcoupling and the compatibility of the substrate with industrial process flows.

Figure 5 shows the demonstrator that was developed in close collaboration with our partners

Solution-processed R2R OLEDs

Roll-to-roll (R2R) solution processing using slot-die coating is a very attractive candidate for manufacturing OLEDs and organic photovoltaic (OPV) modules mainly because with this approach low-cost large area lighting models can be realized in high volume with costs per square meter lower than €100. We have been able to control the layer thickness and uniformity during slot-die coating and drying to give the 30 -100 nm layer thicknesses required for OLEDs with only a few nanometers of layer thickness variation over the device area [3].

For a number of years Holst Centre has demonstrated the feasibility of making OLEDs on both plastic and metal foil substrates. In 2013, Holst Centre and its industrial partners made significant improvements in process conditions to boost device quality and yield. Using metal foils, researchers fabricated R2R solution-processed top-emissive OLEDs measuring 8 cm x 8 cm Through inspection and optimization of each step of the process flow – including material deposition, patterning and packaging – we improved conditions such

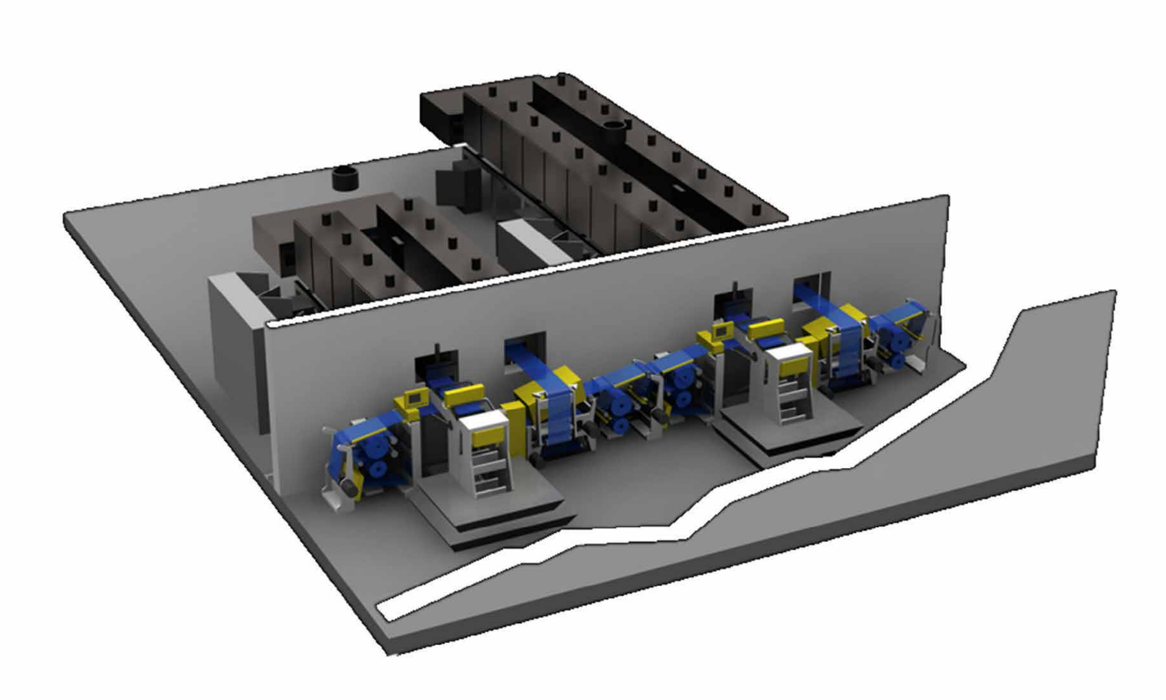


Figure 7:
Solliance R2R Line

as processing speed, layer uniformity and contamination control. The fabricated device showed performance equivalent to small area (2 cm x 2 cm) sheet-to-sheet (S2S) processed devices.

Research on this process will continue at the new Solliance fabrication line in 2014 (a new R2R line aimed to improve throughput and yield of the solution processed devices), leading eventually to volume manufacturing in a production environment and affordable flexible electronics. This new line will enable cleaner fabrication of the devices and is equipped with two slot die coating stations making it easier to coat multiple layers in the same run. The new R2R line has been installed and first tests on the line have already begun.

Conclusion

In order to realize the full potential design freedom of OLEDs for lighting at Holst Centre, we are developing robust S2S and R2R flexible water barrier technologies that will allow flexible devices with a long lifetime. We are also developing large area R2R solution processing equipment, and processes in order to produce such devices at low cost and large volume. We have demonstrated the potential of these technologies, by fabricating flexible and solution processed OLED demonstrators with very good performance.

Acknowledgements:
Holst Centre would like to acknowledge support from our industrial partners and from local, national and European funding.

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InGaN Nanowires Make Light Mixing Efficient and Smart

The correlated color temperature (CCT) of high color rendering index (CRI) LED lighting systems can, in principle, be tuned over a wide range. As an alternative approach to conventional phosphor based LEDs, a full-color LED array consisting of red, green and blue (RGB) InGaN based nanowire LEDs monolithically integrated on a micro-scale level has been proposed and fabricated. J. Lee from the Nano Electronics Lab at the Samsung Advanced Institute of Technology, Renjie Wang, Hieu P. T. Nguyen, Ashfiqua T. Connie, Ishiang Shih, and Zetian Mi from the Department of Electrical and Computer Engineering at McGill University in Montreal explain how this technology works and how the three multi-color subpixels on the same chip can be separately biased and can exhibit full-color emission which can be tuned controllably in a wide CCT range.

The conventional incandescence and fluorescence lamps are limited in terms of their efficiency, lifetime, and environmental impact.
The wide usage of solid-state lighting sources is expected to significantly reduce the electricity consumption for lighting, and reduce greenhouse gases and other pollutions accordingly. Currently, high power LEDs can already compete with conventional light sources. LED-based solid-state lighting sources have also been widely applied for signals and displays. To improve the resolution, optimal viewing distance and color rendering of displays, the technique of subpixel rendering has been commonly used. However, the current phosphor-based white LEDs have been criticized for its low CRI and Stokes fluorescence loss. An alternative approach is to monolithically integrate RGB LEDs directly on a single chip, enabling the tuning of the spectral power distribution. Such a phosphor-free approach can lead to color-tunable LEDs with low power consumption, extremely small size, and high CRI. However, the lack of suitable lattice-matched substrates for the growth of high-In content quantum wells leads to extremely low efficiency of GaN-based LEDs in the wavelength range > 560 nm, severely restricting the device performance including the luminance and tunability of CCT [1]. Moreover, some previously reported approaches for achieving multi-color emission, including the use of vertically stacked multiple quantum well LEDs have significant drawbacks, including the light absorption by adjacent narrow bandgap quantum wells and poor heat conduction.

Compared to conventional planar quantum well devices, nearly defect-free III-nitride nanowire LED heterostructures can be grown directly on lattice mismatched substrates and can exhibit outstanding device performance and reliability.
To date, with the use of InGaN nanowire structures, high-efficiency emissions across the entire visible spectral range have been demonstrated [2-4]. In this context, we have developed laterally arranged RGB LEDs consisting of various InGaN nanowire structures, which provides a high-efficiency approach for subpixel rendering, significantly improving the color rendering index and broadening the color tunability. These monolithically integrated, monochromatic micro-LED arrays, with their sizes in the micron or even sub-micron scale, can readily generate tunable, multi-color emission for lighting and full-color displays.

Growth and Fabrication

To control the composition and dimensions precisely in the atomic level, radio frequency plasma-assisted molecular beam epitaxy (MBE) was used for the growth of nanowires in this work. MBE has reached a high level of maturity and now offers several important advantages for InGaN LEDs compared to the MOCVD growth method, such as in-situ monitoring capability, better interface control and lower growth temperature for the incorporation of high indium compositions. Compared to other material growth/synthesis techniques, MBE can provide the highest control of the structural, electronic, and optical properties of various nanostructures.
In addition, the realization of p-type doping in GaN is more efficient in an MBE growth environment, compared to MOCVD [5]. The unique self-catalytic nanowire growth process we have developed can also minimize the formation of extensive surface defects and unintentional impurity incorporation.

In this work, self-organized InGaN/GaN dot-in-a-wire LED heterostructures were grown directly on n-type Si substrates under nitrogen-rich conditions. The use of large area Si substrate, compared to conventional sapphire substrate, can significantly reduce the substrate cost and improve the throughput. The LED structure consists of ~ 0.4 µm GaN:Si, ten vertically aligned InGaN/GaN quantum dots, ~ 10 nm p-doped AlGaN electron blocking layer (EBL), and ~ 0.2 µm GaN:Mg.
Each InGaN/GaN dot consists of ~ 3 nm InGaN, which is subsequently capped by a 3 nm GaN barrier layer. Our group has previously demonstrated high performance InGaN/GaN dot-in-a-wire LEDs with green, yellow, red and phosphor-free white light emission [6-10].
In this work, such InGaN dot-in-a-wire LEDs, with emission wavelengths in the range from ~ 450 nm to 700 nm, were grown on a single Si wafer using a three-step selective area growth process. As shown in figure 1, three different sets of laterally arranged multi-color InGaN/GaN dot-in-a-wire LED arrays were grown in sequence on a large area Si substrate. For each nanowire LED, the emission spectrum can be readily tailored by varying the sizes and/or compositions of the dots by simply varying the MBE growth conditions.

Illustrated in figure 1(a), a selectively patterned SiOx dielectric layer, with designed microscale openings, was first created on Si substrate by standard photolithography and etching techniques. Blue nanowire LEDs were first grown on the patterned substrate, shown in figure 1(b). The SiO_x mask was then selectively removed, illustrated in figure 1(c). A SiO_x layer was then used to cover the blue LED nanowire subpixels formed on Si, which is followed by the creation of additional opening apertures for the growth of the 2nd step (green/yellow) LED subpixels at desired locations, shown in figure 1(d). Subsequently, the 3rd step orange/red LED subpixels were grown on patterned Si substrates using a similar process, shown in figure 1(e). Finally, illustrated in figure 1(f), the SiO_x mask and nanowires on SiO_x were removed to reveal the three-step nanowire LED arrays. Through extensive studies, we have confirmed that the regrowth steps do not have any negative effect on the quality of the previously grown LED structures. The SiO_x dielectric layer works well to protect the previously grown nanowires from subsequent growths and fabrication steps. Figure 1(g) shows the optical image of the three-step nanowire LED subpixels corresponding to figure 1(f). The three-step RGB arrays were positioned next to each other and sorted in this order as illustrated to enable the seamless integration and light mixing of multi-color LEDs on the chip-level.

Subsequently, nanowire LED devices with areal sizes of 300×300 µm², 100×100 µm2 and 50×50 µm² were fabricated. The RGB pixel size can be readily scaled down to the sub-micron scale. Schematically illustrated in figure 2, p- and n- contacts were deposited on the top surface of nanowires and

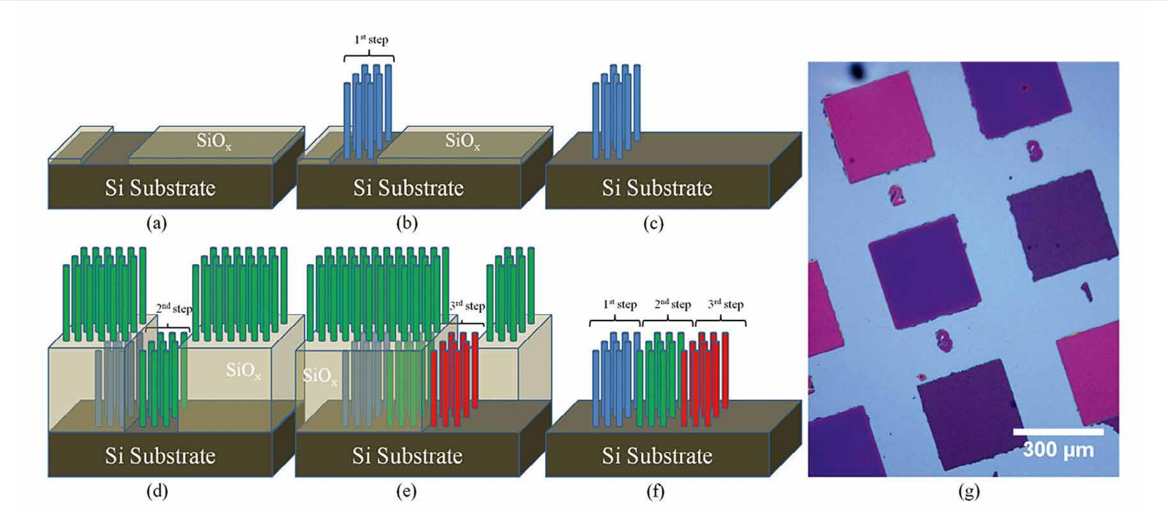


Figure 1: A three-step growth process of multi-color InGaN nanowire LEDs

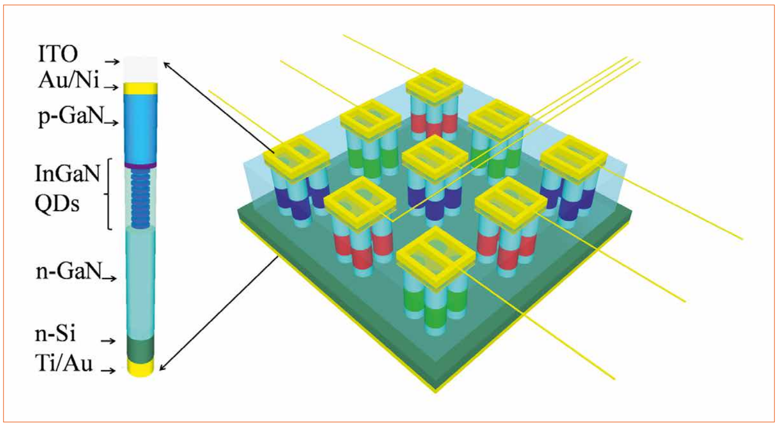
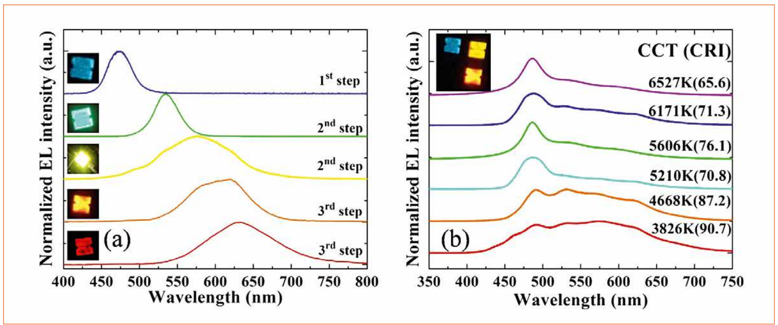


Figure 2: Schematic of a multi-color nanowire LED array



the backside of the Si substrate, respectively. In this study, the multi-color InGaN LED devices exhibit excellent current-voltage characteristics, including relatively low series resistance (~ 20 Ω or smaller).

High CRI and Tunable CCT

In the LED arrays, each full-color LED pixel consists of three multi-color subpixels, which can be separately biased and can exhibit strong emission in the blue, green/yellow, and orange/red spectral range. Consequently, light mixing at the chip level can be readily achieved. More importantly, by varying the injection current to each LED subpixel, the spectral power density and the CCT can be controllably tuned.

Shown in the figure 3(a), tunable electroluminescence (EL) emissions across the entire visible spectral range (~ 450 nm to 700 nm) can be achieved on a single Si wafer. Moreover, for each growth step, the peak position and spectral linewidth of the EL emission, e.g., the green and yellow EL spectra obtained in the 2nd step, and the orange and red spectra in the 3rd step, can be further engineered by varying the growth conditions, thereby providing a great level of flexibility in tuning the emission color of the integrated LED arrays and also leading to full-color LED chips tailored for specific applications. Moreover, each single LED device can be made to exhibit a broad spectrum, due to variations of In compositions in the dots, providing a phosphor-free approach for achieving high efficiency orange, red, or even white light emission with high CRI values.

We have shown that the laterally arranged nanowire LED pixels can exhibit color-tunable characteristics of varied CCTs in the range from 1900 K to 6800 K by independently applying injection current to each LED subpixel. Such monolithically integrated tunable full-color LED arrays also display very high CRI (>90). The output spectra of a representative triple-color LED pixel consisting of blue, green and orange/red subpixels are shown in figure 3(b). It is seen that by adding green and orange/red light components, the CCT can be varied from ~ 6500 to 3800 K. For the operation at CCT of 3826 K, the CRI can be as high as 90.7.

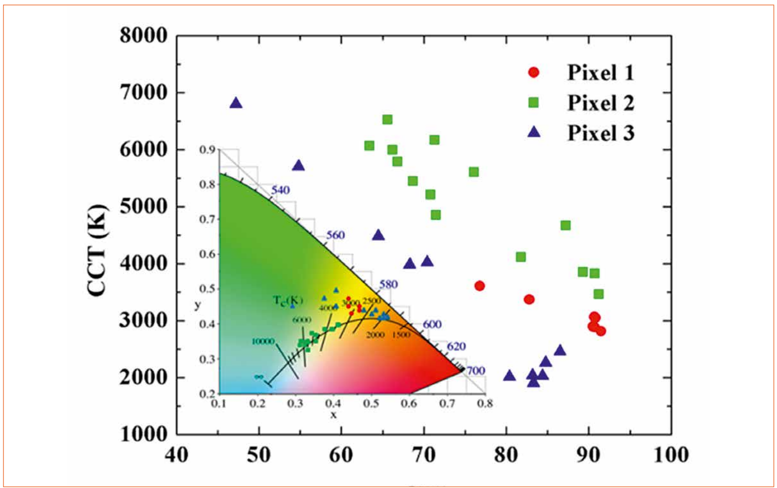
Figure 4 shows the summary of the emission characteristics of three different triple-color LED pixels, which were grown under different conditions. It is seen that the CCT values can be varied from ~ 1900 K to 6800 K. Very large CRI values (> 85) can be achieved for devices with warm and neutral white light emissions (CCT < 5000 K). The output characteristics of these devices are further shown in the CIE chromaticity diagram, illustrated in the inset of figure 4.

High Efficiency and High Onset of Droop

A wide color-tunable range can be achieved at various output power levels. Previously, the achievement of high internal quantum efficiency (~ 60%) InGaN/GaN dot-in-a-wire green, yellow, red and white LEDs has been reported at room temperature [6,7,8,11]. An output power of more than 5 mW was also reported for an unpackaged InGaN based nanowire LED by us [12]. Moreover, the presence of droop under these measurement conditions is relatively small, which is consistent with previous studies on InGaN/GaN green, yellow, red and white nanowire LEDs on Si(111) substrates [6-12]. It has been reported that no efficiency droop was observed for injection current up to ~ 480 A/cm^2 for red nanowire LED [6] and up to ~ 2,000 A/cm^2 [9] for white nanowire LEDs.

Future Research Demands

One drawback of the current design is the light absorption by the underlying Si substrate. It is worthwhile mentioning that today's high brightness LEDs are achieved by removing the underlying sapphire substrate. For practical applications, the underlying Si substrate may be selectively removed by wet chemical etching process to improve the light extraction efficiency. Previously, we demonstrated that nanowire LEDs grown on Si substrate can be readily transferred to Cu substrate [13], which can eliminate any optical absorption by the substrates and



further provide much more effective thermal management. It is also of interest to fabricate monolithically integrated sub-micron scale multi-color nanowire LED and laser arrays on transparent substrate for enhanced light extraction efficiency, directionality, and output power. Such sub-micron scale nanowire LED arrays can be realized by utilizing a combination of nano-imprinting lithography and the afore-described selective area MBE growth process.

Industrialization Perspectives

These miniaturized RGB nanowire LED arrays are well suited for future smart lighting, display, and imaging applications. Such nanowire devices can be readily fabricated in the sub-micron or nanoscale and can also be integrated with Si electronics for applications in projection displays, imaging, and biochemical sensing. The process of making such nanowire devices, including MBE growth and fabrication, only incurs a few hundred dollars per 3'' wafer in the lab level. The cost can be dramatically reduced by utilizing a multi-wafer MBE production system. Using high-resolution lithography techniques, the pixel size of the RGB InGaN/GaN dot-in-a-wire LEDs can be further reduced to ~ 100 nm or smaller. These nanoscale LEDs will be well suited for ultrahigh-resolution display and imaging applications. Based on this work, it is also of interest to develop monolithically integrated color-tunable nanowire surface- and edge-emitting lasers to achieve high power coherent light sources on Si that can operate in the entire visible spectral range, enabling the development of high-performance color-tunable miniaturized laser sources for high brightness and high-resolution displays. ■

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New Class of Siloxane Polymers for Advanced LED Packaging

Packaging presents a major challenge to further improve LED device efficiency and reliability. A novel class of high stability siloxanes forms a technology platform to address such opportunities in die attach, encapsulation, and light outcoupling applications. Dr. Juha Rantala, CEO & Founder, Dr. Joerg Rockenberger, Director Application & Business Development, Dr. Jyri Paulasaari, Vice President Technology, Dr. Jarkko Heikkinen, Director Inks & Pastes. Markus Laukkanen, Application Manager, and Dr. Janne Kylmä, Vice President Engineering & Production at Inkron Oy explain the material properties and give examples of how these new materials in combination with novel nanomaterials enable products fully compatible with current process tools and flows while having superior properties.

New devices and packaging schemes, such as flip-chip and chip and wafer scale packaging, emerge to address issues that limit market adoption of LED products. By that, new materials and integration challenges arise. The novel class of high stability siloxanes, based on proprietary monomers and polymers, is optimized to improve light efficiency individually or in combination and to address new packaging schemes. Proprietary siloxane chemistries provide the basis for stable encapsulation products with a refractive index of 1.62 (at 632.8 nm) increasing package light output efficacy compared to leading commercial encapsulation products.

By combining such high refractive index encapsulants with anti-reflection coatings, light extraction at the package level can be further enhanced. Such multi-layer encapsulation and light outcoupling schemes are particularly well suited for wafer level and chip scale packaging. Further, the proprietary siloxane polymers, in combination with novel nanomaterials, enable die attach products fully compatible with current process tools and flows but with superior heat dissipation and die shear strengths yielding significant improvements in LED device performance compared to commercial die attach adhesives.

Introduction

The efficiency and reliability of packaged LEDs are strongly linked to light extraction and heat dissipation, directly impacting cost per lumen as well as footprint of LED modules and systems. The external efficiency of the LED package is a result of several different factors. One part is the internal quantum efficiency quantifying the ratio of photons generated in the active semiconductor region from the number of electron-hole pairs injected into the LED chip. Internal quantum efficiency is a function of chip junction temperature that is controlled by heat dissipation from the chip with the layer attaching the die to the substrate often presenting the bottleneck for this process. Another factor is the photon extraction efficiency that stipulates the ratio of the photons extracted from the LED chip vs generated at the active semiconductor region. The final part is the light extraction and conversion efficiency at package level. The light extraction at the chip and package level is primarily related to the index of refraction of the encapsulant as well as the use of secondary light outcoupling optics, e.g. micro lenses, diffractive lenses or dome lenses. In white light LEDs, the encapsulant's refractive index also impacts scattering losses within the phosphor wavelength conversion layer.

Recognizing the impact of optoelectronic packaging materials like encapsulants and die attach materials on the factors outlined above, they have advanced over time from organic epoxies to organosilicon polymers such as methyl and phenyl silicones. However, present commercial solutions are not sufficient to address all needs in high power LED and new packaging schemes such as flip chip packages in terms of optical properties, barrier properties, thermal stability and process temperature. Novel and proprietary siloxane polymers can address these requirements and challenges and are therefore potential candidates as advanced packaging materials. We report here a new class of proprietary siloxane polymers presenting a technology platform for high refractive index encapsulants and low sintering temperature die attach materials.

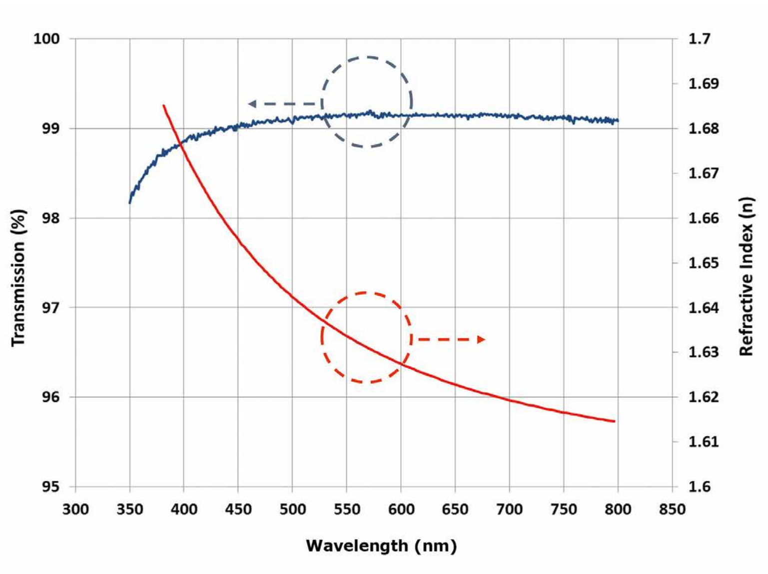


Figure 1: Transmission curve (blue) and refractive index dispersion curve (red) for a film of 70 um thickness formed the ILE-501 LED encapsulation product. ILE-501 part A & B were mixed in 1:1 ratio in a Thinky Planetary Vacuum Mixer for 2 minutes at 1400 rpm at 1 kPa. Glass slides were coated and the sample cured at 150°C for 60 min.

Product	Material	RI	lm	Water	Air	Sulfur
ILE-501	Novel Siloxane	1.65	100	1	1	1
ILE-501 +ARC	Novel Siloxanes	1.65 +1.4	103	NA	NA	NA
Reference 1	Phenyl Silicone	1.54	94	4.1x	8.7x	8.3x
Reference 2	Methyl Silicone	1.41	90	22.4x	>130x	18.3x

Table 1: Comparison of three different LED encapsulation products regarding their refractive indices and its impact on the relative lumen efficacy of 2 W PLCC multi chip packages as well as their relative permeability against water, air and sulfur vapors

Siloxane Encapsulants

The optical power output efficacy of an LED device is, in part, limited by the amount of light extracted from the active semiconductor region of the chip as briefly mentioned above. A key factor in this regard is the interface between the high refractive index semiconductor substrate and the surrounding media, e.g. air or conventional methyl or phenyl silicones (e.g. refractive index of 1.4 - 1.55 at 633 nm). The smaller the difference in refractive index the less light is lost to internal reflection in the chip increasing the light output efficacy of the LED device. The new class of siloxane polymers described here yields a first generation LED encapsulation product, ILE-501, with a refractive index of 1.62 and 1.65 at 633 nm and 450 nm wavelength, respectively, and with superior barrier performance against environmental degradation offering significant opportunities to improve the light output efficacy as well as reliability of LED modules and systems.

The optical properties of this product were characterized by UV-VIS absorption spectrometry (Perkin Elmer LAMBDA 25 UV/VIS Spectrometer) and spectroscopic Ellipsometer (J.A. Woollam α-SE™) and are shown in the following Figure 1 (blue: transmission curve for a film of 70 um thickness; red: refractive index dispersion curve). As indicated the characterization reveals a refractive index of 1.62 at 633 nm wavelength that increases to about ~ 1.655 at 450 nm. Throughout the visible wavelength range, the film shows a very high transparency of over 99% that in combination with its high thermal stability makes this product well suited for mid- and high-power LED applications requiring long device lifetimes.

To illustrate the impact of the optical properties of the new Siloxane material on the performance of LED packages, plastic leaded chip carrier (PLCC) multi chip packages were encapsulated with ILE-501 and phenyl (Reference 1) and methyl (Reference 2) silicones with a refractive index of 1.54 and 1.41, respectively. In addition, a multi-layer encapsulation scheme was tested, wherein an ILE-501 encapsulated LED package was coated with a proprietary siloxane based anti-reflection coating (ARC) with a refractive index of 1.4. In all cases, a commercial YAG phosphor was mixed with encapsulant material, the color temperature was adjusted to 5,000 K and the packages were identically processed and operated at 2 W electrical power.

The results of the evaluation are shown in table 1. Water vapor and oxygen transfer rates were determined following ASTM F-1249 and ASTM D-3985 measurement protocols. The permeability to sulfur vapor diffusion was determined by measuring the reflectance of encapsulated silver films before and after exposing the samples to sulfur vapors for 24 hours at 70°C (samples enclosed in 100 ml bottle with 0.2 g of sulfur) with a Perkin Elmer UV-VIS Lambda 950 spectrometer with integrating sphere.

As can be seen in Table 1, the new encapsulation product with a refractive index of ~ 1.655 at 450 nm resulted in 6% and 10% higher lumen output efficacy compared to commercial phenyl (Reference 1) and methyl (Reference 2) silicones. The sample utilizing a multilayer encapsulation scheme “ILE-501 +ARC” showed an even higher output efficacy illustrating the importance and potential of carefully engineering the optical interface between the LED chip and the environment for the performance of LED modules and systems.

Further characterization of the new siloxane polymers revealed that they form improved barriers against environmental influences (e.g. air, water and sulfur) compared to conventional methyl and phenyl silicone products. Table 1 summarizes the results of measurements of the water vapor and oxygen transfer rates as well as corrosion resistance of encapsulated Ag films upon exposure to sulfur vapors for Ithe new and two commercially available and commonly used reference products. The results are normalized for ILE-501 and show that both commercial products have higher permeability for oxygen as well as water and sulfur vapors than ILE-501. The superior barrier performance may, in particular, be of commercial significance for novel narrow bandwidth red phosphors and quantum dots with high environmental sensitivity. But also conventional phosphor applications may benefit from this aspect as illustrated by exposing silver plated leadframe packages using the three encapsulant products to sulfur vapors in an accelerated lifetime test. Within 24 hours at 70°C, packages encapsulated with methyl and phenyl silicones turn black due to silver corrosion whereas packages encapsulated with ILE-501 remain silvery and shiny (data not shown). This superior performance illustrates the potential impact this new class of siloxane polymers can have for the long term stability and reliability for a wide variety of LED modules and systems.

Siloxane Die Attach Materials

In order to maximize the efficiency of a LED chip, it is key to lower the chip junction temperature by utilizing better interconnect materials at packaging level or by reducing thermal barriers between the chip junction and substrate in other ways. A significant portion of the junction-to-substrate thermal resistance comes from the joint between chip and substrate, the die attach layer. The thermal resistance of this interface layer is determined by its thermal bulk conductivity and boundary resistance as well as thickness of the die attach layer.

Leveraging the same novel proprietary siloxane polymer platform as for optical encapsulation products described above, several versions of novel siloxane-based die-attach materials have been developed. Addressing various LED packaging schemes, the die attach product line includes reflective electrically conductive, reflective electrically insulating and transparent electrically insulating materials. The novel siloxane polymers are used as a matrix in these products due to their excellent thermal and light stability over the conventional epoxy binders but also due to their great adhesion via covalent bonding to various metal and oxide surfaces. Improved adhesion has benefits for device reliability but also increases heat transfer between the chip to die attach layer interface as well as the die attach layer to package interface.

Here we present a comparison of two novel siloxane-based die attach products against two market leading reference materials. The first case study includes IDA-125, an electrically conductive die attach material comprising siloxane polymer as a binder and in-house synthesized silver particles as a filler. This product can be cured at 150°C in 30 minutes by a pressure less method making it attractive for applications requiring fast processing. As a reference, a commercially leading silver sintering die attach product was selected requiring processing at 200°C for 60 minutes. Bulk thermal conductivities were measured using a Netzsch LFA 467 laser flash analysis tool and the junction-to-substrate thermal resistance was determined with a T3Ster thermal tester (Mentor Graphics) from a 75 W UV chip-on-board (COB) LED module (Figure 2). The total heat dissipation of the tested module is about 50 W at a heat dissipation density of about 20 W/cm^2. Furthermore, both materials were tested for die shear strength according to Mil-Std-883 Method 2019.7 standard.

The bulk thermal conductivities of the IDA-125 and reference die attach products as determined by laser flash measurements was 25-30 W/mK and 40-60 W/mK, respectively. Obviously, the reference material showed substantially higher bulk thermal conductivity, presumably due to higher silver content and more aggressive curing conditions. A comparison of the bulk thermal conductivities may lead to the conclusion that this reference product may be a superior solution for efficient heat dissipation in power LED applications but it fails to take into account the role thermal contact resistance plays in the thermal performance of the overall LED package. In fact, measurements of the thermal impedance of the chip and die attach layer for the two products were close to identical and below 0.2 K/W at comparable bond line thickness (BLT) of 15um (Figure 3). In correspondence with this characterization, the optical evaluation of the LED COB modules using the two die attach products showed identical results with optical power output efficacies of 34% and light output of over 25 W at 385 nm wavelength. However, illustrating the superior interface quality using the IDA-125 die attach product the die shear strength was determined to be 2 times higher than with the reference product. The higher die shear strength at lower processing temperatures of the IDA-125 product compared to the reference product while providing similar overall heat dissipation and hence optical performance despite the lower bulk thermal conductivities is a significant advantage and illustrative of the potential this class of new siloxane polymers has for die attach or for thermal interface materials in general. The low processing temperature of the new Siloxane based material compared to conventional silver sintering products also opens the door to applying such product to conventional plastic lead frame packages providing superior heat dissipation characteristics previously not attainable.

Figure 2: LED chip-on-board (COB) module (75 W) comprising 63 385 nm UV chips in a 7x9 configuration on an aluminum ceramic substrate utilized for thermal resistance testing of IDA-125 and a commercial reference product

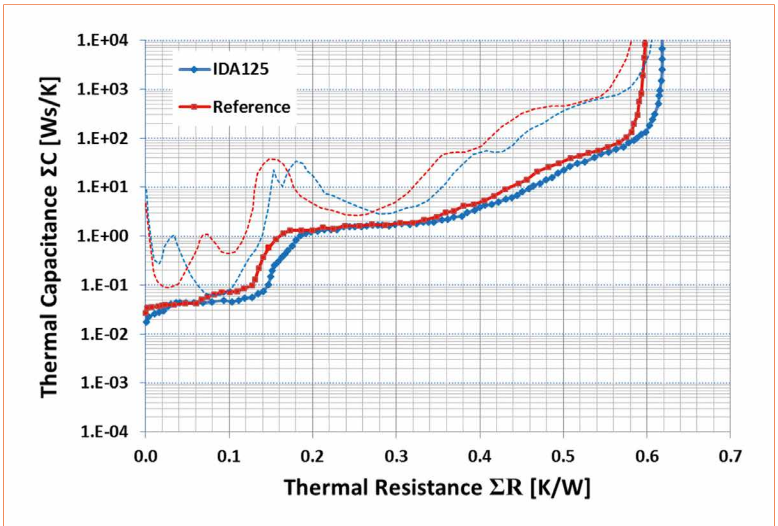


Figure 3: Thermal resistance comparisons as cumulative structure function for 75 W LED COB modules with IDA-125 and reference die attach products

The comparison in figure 3 shows a very similar thermal (and optical) performance despite IDA-125 being cured at significantly lower process conditions (30 min. at 150°C) than the reference product (60 min at 200°C). In contrast, IDA-125 shows higher die shear strength (2x) than the reference product illustrating the superior interface quality of the new material.

In a second case study, a new transparent electrically insulating die attach product, IDA-313, comprising novel proprietary siloxane polymers and ceramic filler, is compared to a leading transparent silicone die attach adhesive. Both products utilize the same pressureless curing conditions (60 min. at 150°C) yielding films with thermal conductivities of 0.5 W/mK and 0.2 W/mK as well as transparencies of >90% (2.5 um film) and >99% (5 um film) for IDA-313 and the reference product, respectively.

LED packages were formed using both products for attaching sapphire LED chips to copper-nickel-silver contact pads on alumina substrates with bond line thicknesses of 1.5µm and 4 um for IDA-313 and the reference product, respectively. Relative lumen output at 1 W electrical power and junction temperatures at environmental

Product	Material	BLT [um]	lm	Die shear strength [Kg]	Junction temperature at 25°C [°C]	Junction temperature at 85°C [°C]
IDA-313	Novel Siloxane with ceramic filler	1.5	100	3	54	116
Reference	Silicone	4	97	1.4	62	124

Table 2: Comparison of the relative lumen output, die shear strength and junction temperature of sapphire LED chips attached to alumina substrates using transparent electrically insulating IDA-313 and a leading commercial silicone die attach product

temperatures of 25°C and 85°C were measured for both types of LED packages. In addition, the die shear strength of the LED packages was determined at room temperature. As seen in Table 2, the IDA-313 product showed two times higher die shear strength than the reference product even though the bond line thickness was one third of the reference. This thin bond line thickness in combination with the >2x higher thermal conductivity of the material itself resulted in higher lumen output (3%) and lower junction temperatures (Δ -8°C) for IDA-313 compared to the reference die attach product. Therefore, the new siloxane polymer based die attach products provide superior optical performance and higher reliability due to better adherence to the LED die and interconnect substrate when compared to commercial reference products.

From the above two case studies, it can be concluded that the quality of the interface between the die attach layer and the substrate as well as the LED chip has a profound impact on the thermal and mechanical performance of the LED stack and that these aspects need to considered in addition to bulk thermal conductivities when designing and manufacturing mid and high power LED and COB modules.

Conclusions

Novel and proprietary siloxane polymers provide a technology platform for a range of improved products for conventional LED packaging and addresses challenges and opportunities in emerging packaging schemes. New LED encapsulant and die attach products significantly increase the efficiency and reliability of LED devices advancing the market adoption and penetration of LED applications by lowering the overall cost of modules and systems while meeting or exceeding current performance requirements.

Lightfair 2015 – A Grand Show with Work Still Remaining

This year's Lightfair USA was held in New York at the beginning of May. Dr. M. Nisa Khan, President of IEM LED Lighting Technologies, visited this leading event for LED professional. This report includes what attracted her attention, the conclusions she drew and an idea of the current status of LED lighting. She shows what has been achieved and which hurdles still need to be tackled.

Lightfair 2015, in New York City was a spectacular show during a week of perfect, sunny, spring weather after a long and difficult winter that shrouded the Northeastern region of the United States. The biggest annual architectural and commercial lighting trade show brought an energetic crowd together that seemed anxious to bolster the lighting business at an unimaginable velocity. Riding on the enthusiasm coming from "The International Year of Light", the show brought many related industry and academic professionals whose participation has bolstered the field of lighting even further. This year's show broke all previous records: Nearly 30,000 attendees and 599 exhibitors occupied the largest floor space ever - 268,580 square feet! Just as last year, the show was all about LED lighting.

About the LED Lighting Growth Sustainability

Everyone recognizes that the popularity of the lighting industry s due to LEDs. LEDs' success in the display arena has been astounding and is well deserved indeed. The improvements in lamp efficacy and color continue to be remarkable; and lighting controls have reached a wondrous plateau due to LEDs' unique electronic tuning capability. All these benefits coming without any known hazardous substance like mercury found in all gas-discharge lighting products, seem to have established LED lighting as a greener technology over all incumbent lighting products. Sounds like an easy and straightforward declaration that LEDs will dominate the lighting industry in the foreseeable future, right? At least some lighting experts would argue that it will not happen very quickly. Among the showstoppers are glare from LED lamps and their difficulties in achieving the desirably uniform light distribution that general lighting applications have had for over 100 years from traditional lamps.

Scientific and technological breakthroughs have profoundly changed human lives from time to time. Visionaries have sometimes guided the ways these unfurled, energizing societies to look forward to more prophecies as humankind has progressed. But certain visions or claims never materialized, despite their tantalizing sound bites because they simply violated fundamentals. Fundamentals should be utilized as solid pillars to discredit any vision that violate them despite their seeming exuberance. Let's look at a few such visionary claims.

Less than 20 years ago, at the turn of the last millennium, we were in the midst of the dot-com boom. The exuberance was created as fiber-optics communication became so successful that many people believed fiber bandwidth is essentially free and limitless, and data transfer or the means of communication could be achieved via fiber everywhere at all times. The enabling technologies behind this were fiber-based networks and data transport through optical wavelength division multiplexing (WDM) techniques. Consequently, visionaries claimed that fiber connection would reach each and every home and furthermore, WDM would bring data to the desktop. Such a claim never panned out despite the cost reduction and glut for fiber bandwidth that were present. Why didn't this vision ever become a reality? It is because fundamentally, copper is a winner over fiber for short distances; it has sufficient capacity over short distances and it is far less expensive and easier to deploy compared to fiber. Moreover, as mobility became very desirable by individuals and all-wired network was no longer appropriate, a suitable combination of fiber, copper, and wireless network adoption became the enabler, allowing individuals as well as homes and workplaces to have mobile connectivity. The lesson is: Know your competition!

Another such example comes to mind. When small aircrafts such as helicopters were first built, some thought people would fly their personal helicopters to grocery stores when the cost of such aircrafts sufficiently decreased over time. Of course this example is now easy to understand; as neighborhoods formed with a certain population density, the infrastructure allowing people to fly their personal helicopters to grocery stores was not realistic regardless of what the cost of the helicopters may be reduced to.

How about the claim of LEDs virtually replacing all mainstream lighting? Despite LEDs success in certain applications and some inherent advantages that include efficiency and electronic tunability, LED lighting stands to face obstacles in becoming the dominant choice for general lighting purposes. Focusing on "smart lighting" appears to be avoiding primary challenges in order to entice users with secondary features and that may not be long-lasting. In my view, it is a just a matter of time before the lighting industry and regulatory bodies establish the metrics that will properly determine primary features of lighting aside from color properties; these are quality, comfort, balance, and system efficacy with regards to intensity levels and spatial distribution. Although most attendees, including many speakers and exhibitors did not acknowledge that current LED technologies face these challenges, a small minority group at this year's Lightfair did provide some small signs that these should be the focus of LED lighting moving forward. Here are my observations from Lightfair 2015 that establish that while the lighting industry recognizes these issues, there is still work to be done on understanding LED illumination.

Hurdles to Overcome for LED Lighting

Although LEDs are undoubtedly beneficial for such applications as backlighting, LED electronic displays, architectural and certain task lighting, inorganic LEDs' current form is not well-suited for large area lighting in living space due to their inherent light distribution properties. Inorganic LEDs have directional and concentrated light that inherently has a Lambertian-type intensity profile and therefore do not provide uniformly broad illumination. Many lighting designers struggle to distribute light from LED lamps and LED luminaire designers also find it very difficult to broaden light uniformly over large volumetric space. I elaborate this challenge later in this article with some feedback from certain speakers at Lightfair. OLEDs, in principle, do not face such disadvantages and for this reason, OLEDs continue to remain an attractive option despite their own durability challenges amid temperature and humidity. In spite of the fundamental glare and light distribution challenges of inorganic LEDs, the lighting industry in unswervingly moving ahead with LED replacements in numerous general illumination applications that include street, warehouse, office and residential lighting. In my view, there are a number of reasons why such LED adoption is accelerating despite the adversities that still remain.

The adversities of LED technology include the following 3 challenges and 4 benefits:

- To a large degree, spatial light distribution is invisible to the eye and appearance of illumination is subjective
- Lack of standards
- Lack of understanding, quantifying methods and metrics that determine light quality
- LEDs use less energy and are dimmable in contrast to fluorescent and other gas-discharge lamps
- LEDs do not contain mercury
- LEDs are electronically controllable to offer variable CCTs to suit human circadian rhythm
- LED luminaires are more integration-friendly to include wireless communication system on chips

The benefits described in the last 4 bullet points are, of course, meaningful reasons for preferring LED lighting. But what about the three challenges? Numerous people I talked with at Lightfair, especially lighting designers, resonated with these challenges and have expressed their frustration that no solutions for them have been found as of yet. So why are LED replacements forging ahead? As one attendant pointed out at "LED and Advanced LED Luminaire Design Courses" (L15L07 & L15L10), this is due to a lack of standards. I would agree and would elaborate that any LED replacement forging would have failed if the lighting industry had a set of criteria in place that spelled out what light levels and distributions are beneficial, and therefore required, in various day-to-day illumination applications. Although lighting is by-and-large subjective, many people do appreciate and desire certain lighting characteristics for various uses. The lighting industry has done a very good job describing the color properties and establishing their metrics for white light and there is a reasonable correlation between these and what the average population generally prefers. However, the existing metrics regarding spatial light distribution and light intensity levels are

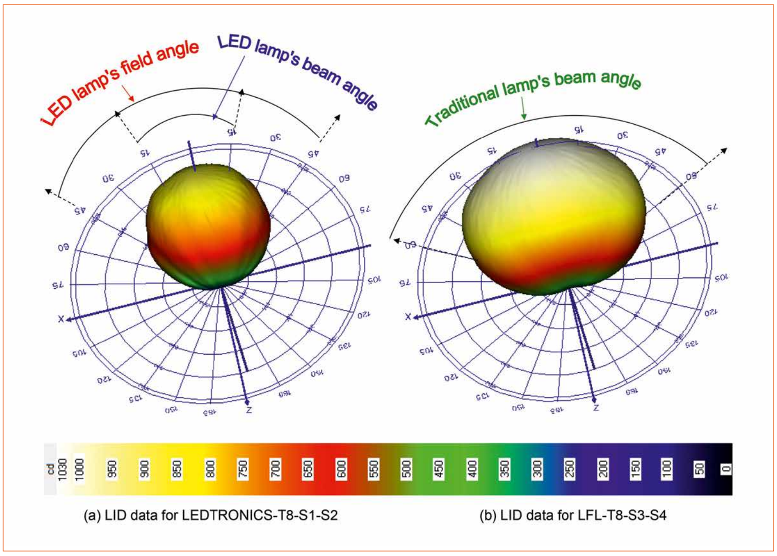


Figure 1: Comparison of the light distribution of an LED tube lamp (a) and a linear fluorescent lamp (b) [1]

inadequate and there is a large variation among what lighting experts and designers understand, appreciate and agree on with respect to light intensity and spatial distribution. In general, the average person is neither able to identify these requirements nor can come to a consensus with others in any straightforward manner in a short period of time. Although many people are unable to distinguish high quality lighting right from the start, it is important to note that, over time, many of them do recognize inappropriate lighting characteristics, such as high glare and inadequate illumination in certain areas – sometimes within the timeframe of a week.

LED lamps have met the challenge of color rather well. We can now find commercial LED lamps with a wide range of CCT ranging from 2800 K to 5500 K or even much higher; CRI ranges from 85 to low 90's while maintaining efficacy over 100 lm/W. These color performances easily surpass those from many commercial gas-discharge lamps. However, with respect to intensity levels and spatial light distribution, LED lamps are substantially underprivileged compared to traditional lamps and luminaires. The problem, though, is that the lighting industry is not yet able to quantify such inadequacies. Sadly, the outcome now, is that an LED replacement lamp with only good color performance and with total lumen output matching that of an incumbent is deemed appropriate regardless of its spatial light distribution characteristics!

In my view, currently there are five specific topics concerning LED lighting quality that must be brought to attention. Interestingly, several notable speakers, exhibitors, and the audience attending key lectures made concerning comments related to these topics. I now address these topics with some supporting feedback obtained from Lightfair.

LED beam angle specification is not sufficient

Although there is a metric called "beam angle" that is commonly used to help establish how widely the beam from a lamp spreads, the industry hasn't provided a clear definition of it as of yet. Because it is not properly defined or differentiated among the lighting and optics disciplines, the beam angle metric used by LED and optics professionals is not yet effective for assessing LED lamps for lighting.

Until the advent of LED lamps, lighting professionals have been accustomed to lamps that spread light homogeneously over an angle referred to as the "beam angle" that is typically quite broad; in other words, luminous intensity from a lamp or luminaire stayed largely uniform over a very broad angle for general purpose lighting. This is best depicted in a 3D LID (luminous intensity distribution) data from an incandescent lamp or a tubular fluorescent lamp. Figure 1b shows the uniform beam spreading measured from a pair of fluorescent lamps. In contrast, figure 1a shows that the measured LID from two replacement LED tube lamps that spreads over a much narrower angle and the beam spreading is substantially uneven over this angle. In figure 2, the 1-dimensional, cross-section intensity profiles, a and b, of the two cases in figures. 1 a & b are schematically shown to demonstrate the degree of uniformity.
The quantitative comparison of this kind is far more useful to understand the intensity non-uniformities among lamps than using photographs from regular cameras. The luminous intensity distribution, as that shown in figure 1b, can be placed in troffer-type shades to create luminaires that produce "bat-wing" type distributions, which spread over an even broader angle than 120 degrees as shown in figure 1b. Such bat-wing type LID is very well-suited for illuminating large rooms with high-ceilings.
In contrast, most LED replacement tube lamps, despite producing more lumens and more lumens per watt, have distributions similar to that shown in figure 1a, thus posing a problem for lighting designers to uniformly illuminate large rooms.
It is important to realize that lighting designers are not able to produce any further broadening of LID, bat-wing or otherwise, from that shown in figure 1 a with any external luminaire shades. Figure 3 a shows that surface light levels or illuminance are too high directly below the LED luminaires while they

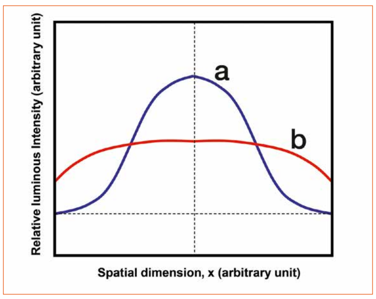
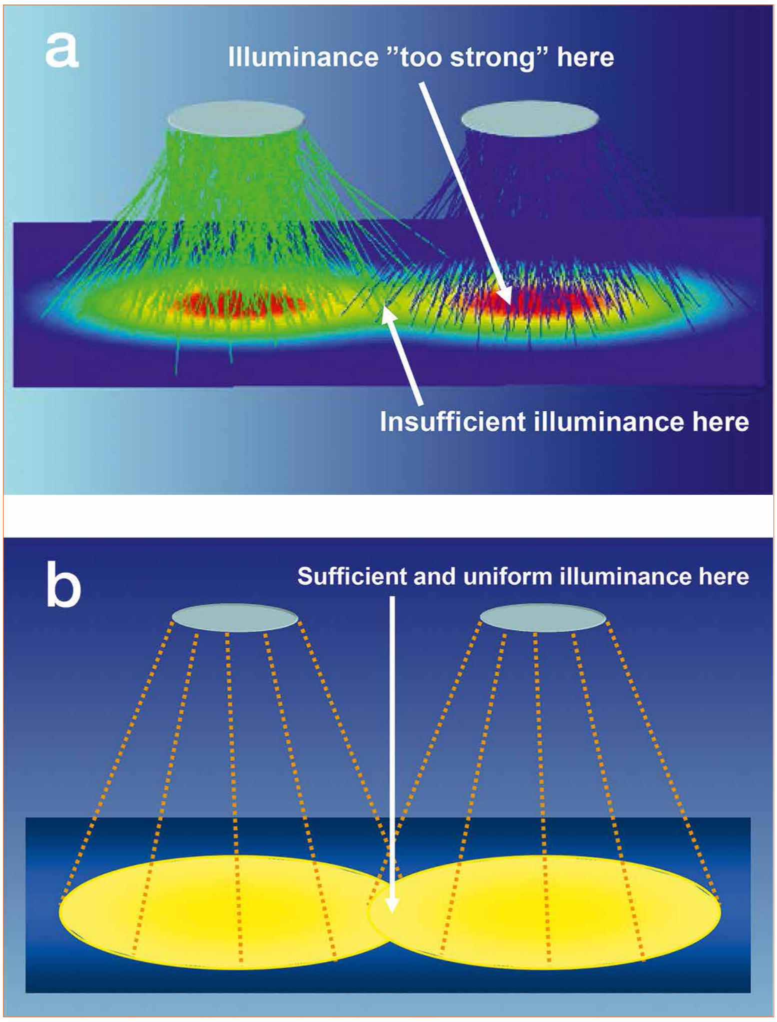


Figure 2: Schematics of one dimensional cross-section intensity profiles of LED lamp (a) and traditional lamp (b)



Figures 3 a & b: Simulated illuminance of two LED lamps and two traditional lamps on a plane below the lamps

are insufficient in the middle of two LED luminaires when compared to the case with traditional lamps in figure 3b.

In the LED or optoelectronics community, the term "beam angle" is widely used to define the Full-Width at Half-Max (FWHM) spreading angle – meaning the angle specifies where the beam intensity drops to half its peak value. However, in the lighting community, such a description is completely foreign and in fact not very useful. Therefore, when LED scientists and engineers as well as optics designers use the term "beam angle", most lighting professionals naturally misunderstand the term and tend to interpret that the term refers to the angle over which the luminous intensity remains largely uniform, which is not the case. In many lighting applications, it is imperative that the beam intensity remains fairly uniform or constant over a specified angle. Therefore a typical LED lamp that has a variation as drastic as a cosine profile over this specified angle is simply not effective for many lighting design cases. In fact, some in the LED lighting industry now are defining yet another term called "field angle". This angle defines the angular spatial region where the entire or a substantial part of the entire intensity from the lamp is confined. Bob Householder, from Universal Lighting, discussed this term in his part of the lecture in the "LED and Advanced LED Luminaire Design Courses" (L15L07 & L15L10). Because LED lamps' light output from the original emitter or source is always of the Lambertian kind, no matter how any parameter, whether beam or field angle, is defined – the intensity distribution in the angular domain is largely non-uniform due to the cosine-like profile. Our naked eye, especially an inexperienced one, is unable to distinguish light distribution characteristics from lamps – whether it is a cosine profile or primarily flat over angular domain, especially through initial glancing. Therefore, naked-eye judgements should not be used to qualify lamps' intensity profiles for real applications. Taking photographs of light spots is also not a proper way of determining intensity characteristics because intensity levels are not displayed accurately enough in films or other printed media. Looking at a simulation showing intensity patterns in various colors is also not effective unless we know what intensity levels are desirable and suitable in the first place.

Aram Ebben from Exp U.S. Services Inc., in his part of the presentation, "SSL Beyond Efficacy" objected to the usage of "beam angle":
He elaborated the inappropriateness of using the term in LED light distribution because over such an angle the beam is not as uniform as that found in beams from traditional lamps. He used gray-scale photographs to differentiate the intensity profiles from lamps on a 2D plane. Although such a distinction is noticeable, one does not get the true picture regarding how the two cases are different quantitatively. Lighting professionals need to quantify these differences to obtain illumination design solutions in the real world.

Because LED emitters produce a Lambertian type intensity profile, it is easy to collimate them and create LED spotlights that are somewhat equivalent to PAR and MR type lamps.

I have noticed two problems with these LED replacement lamps at Lightfair and along the streets of Manhattan:

- Some do not use collimating lenses and therefore the beam remains the Lambertian type and therefore provides a non-uniform spot illumination
- Many such spotlights are incredibly glary – far more than traditional PAR lamps

The industry must determine what luminance and luminous intensity are required for certain spotlight applications and design LED replacement lamps accordingly without wasting lumens and make sure these lamps do not cause disability glare. These standards are yet to be established.

The underlying problem in not figuring out why LED lamps have fundamental challenges is that the majority in the industry still does not have clarification on the distinctions among these light metrics: luminous intensity, luminous intensity distribution profile, luminance, and lumens. Many instructors as well as exhibitors at this year's Lightfair relentlessly claimed "lumen" or "light power" is the only parameter that really matters. But "lumen" as a sole parameter does not provide the illumination criteria. Although it has been talked about that "light distribution" is what's important, the lighting industry technically has not specified or clarified what light distribution is required for a particular illumination design.

Differentiate optics from light, and light from lighting

At the heart of understanding illumination as well as understanding LED illumination is the important concept of distinguishing the 3 separate fields: optics, light, and lighting. Although many lighting professionals have always appreciated the distinction, scientists and engineers working on optics, optoelectronics, photonics and light typically do not fully appreciate the distinction. They tend to focus on light generation and certain behaviors of light; however light distribution and intensity levels for the purpose of illumination involving human perception of light are not topics they generally engage in.

Without such focus as well as standards that spell out illumination criteria, the lighting industry has been caught in somewhat of an ineffective plateau in the advent of LED lighting that comes with many challenges, benefits and increasingly affordable lumens. The LED industry has made very good progress recently with regards to differentiating optics from light. However what remains is still differentiating light from lighting.

Mark Rea, Director of Lighting Research Center (LRC at Rensselaer Polytechnic Institute) in his impact speech, "Monetizing the Benefits of Lighting" described the differentiation well. He called light the commodity and lighting the final product, drawing on the analogy that barley is the commodity and beer is the product people know, appreciate, and consume. He said it is the specific companies and brands who brought many different elements together to create beer - the final product that people now appreciate, trust, and relate to; these include the can and bottle designs, markings, and the right recipe. When people consume beer, they hardly think about barley - the key ingredient; but they know what beer is rather well. Similarly, lighting is what people intake while light is only the commodity. The difference here though is that lighting happens to be more subconscious as well as subtle!

Similarly, it is important to recognize the following: the optics domain has traditionally included light generation and characteristics studies; light is the commodity generated; and lighting is the final usable artifact people appreciate and consume. Along with the significance with how these are connected, it is also important to differentiate them with regards to relevant quantity and quality.

Lighting, the final artifact, has been created for many years to illuminate space so that we can visualize objects and our surroundings. We now have the opportunity to create lighting incorporating such additional goals as energy and resource savings, protecting environment, safety of people and other living beings, as well as curing ailments. These may be brought into a measure called the "benefit factor". However, in my view, such a factor should not override the very basic purpose of lighting that we have been accustomed to.

LED pixilation should be avoided

Although not a popular subject, some lighting professionals are trying to identify elements that make certain LED lighting not very natural or aesthetic. Some are working on whether such deviation from natural appearance is linked to adverse photobiological affects. Glare is obviously one such undesirable feature. Another is dot or pixilation visibility in lit LED lamps. L. M. Geerdinck et al. from Philips Research addressed the influence of pixilated light sources on glare in "Discomfort Glare Perception of Non-Uniform Light Sources in an Office Setting" published in LpR 44. Because inorganic LEDs are made of small, flat chips – many of them need to be mounted in arrays on flat surfaces in order to create a lamp or luminaire that can produce appreciable amount of lumens for specific applications. Many lamps configured with these individual LED modules generate a pixilation affect visible to the naked eye. Mark McClear from Cree, in his part of the lecture in the "LED and Advanced LED Luminaire Design Courses" stated that pixilation should be avoided. In most cases, pixilation is discouraged and in certain applications pixilation is not allowed.

There are currently two main ways of avoiding pixilation:

- Chip-on-Board or COB configuration
- Translucent covers over the LED modules

Neither is a satisfactory solution because the COB solution faces thermal management, manufacturing, as well as acute glare challenges while translucent covers degrade lamps' luminous efficacy. Satisfactory solutions can be achieved by understanding why

LEDs inherently produce a Lambertian light output and glare. Such understanding will lead to luminaire and lamp designs that avoid producing a Lambertian light output in the first place.

Beware of blue light hazard and benefits

Benefits and adversities of light containing blue wavelengths have been popular medical subjects in recent times. Photobiologists and certain medical professionals have written about nighttime blue light exposure that can disturb the circadian rhythm and thereby causing an array of physiological harm to humans; studies have also shown blue light can be used to treat seizures and other diseases. Dr. Joan Roberts from Fordham University discussed these in detail in the lecture “Blue Light – Therapy and Risk” (L15S14) referring to some latest studies.

While the presentation provided valuable information with regards to understanding harm caused by specific blue wavelengths and aggregation affects over certain wavelength spectra, it fell short of providing any information on blue light intensity levels and duration that one should avoid. After several questions from the audience in this regard, Dr. Roberts declared that not enough studies were done on the topics. Although she touched on the glare problem, when asked whether any luminance levels were recommended from studies for avoiding glare, she replied that lumens was the cause of the glare problem and not luminance! Thus it became clear that indeed understanding and obtaining luminous intensity data were still needed to deepen photobiological studies further.

Why incandescent is still the most artistic light

In the advent of LED lighting, it has been popular to degrade the incandescent lamp around the world. An instructor from the “Advance LED Luminaire Design” course used several slides to declare such a lamp should not be used any longer. Of course the ban on incandescent lamps in many countries around the world is now a reality and the remaining countries seem eager to follow suit. It was refreshing to hear Howard Brandston, former president of IES, state, in his interview with Chip Israel, that he regrets seeing the incandescent lamp being banned. He also stated that LED lamps are useful for certain applications and claimed that “there are no bad lamps, only bad applications” and added that there is no matching of the incandescent lamp’s highest quality, used with color filters, in theatre lighting!

Such a claim is indeed fascinating and valid in my view as well. Howard Brandston is a long-time, decorated lighting designer and a lighting legend. Among his many accomplishments and talents, he is known for authoring the book, “Learning to See, A Matter of Light”. Apparently he sees light from incandescent lamps that others tend to miss. Although he did not explain in his interview at Lightfair why the incandescent lamp produces illumination that is superb for theatre lighting, I suspect that aside from color properties, it also has to do with spatial light distribution. I would say that Brandston means the unique light distribution from the incandescent lamps produces light and shadows just in the right places on theatrical subjects and objects, creating beautiful artistic affects.

Current LED lamps cannot create such light distribution because LED light distribution is Lambertian or some modified form of it, which is not gradual and uniform such as that from incandescent and gas-discharge lamps. While most people are not very keen on the light distribution aspect of illumination design, many artists, photographers, cinematographers, and theatre lighting designers do see spatial light distribution as a vital component for illumination.

There are actually scientific reasons why the incandescent lamp produces a light distribution that illuminates 3D objects with gradual light and shadows while the current LED lamps do not. So the lighting industry has two choices: we either need to be as good as seeing the light as Howard Brandston or use mathematical descriptions of what good spatial light distribution is or and set illumination standards accordingly! Let me elaborate this point with other discussions that took place at Lightfair. A gentleman from the audience asked Bob Householder, during his presentation, how difficult it really is to broaden light uniformly from an LED luminaire or lamp. Householder said, “It is really difficult!” Then he said, “It’s not that difficult.” However, he never gave a description of a method or a rule for really broadening light uniformly in space from an LED lamp. Nor did he share a design that accomplishes this either in class or in his handouts. While many people may think that it can be done in principle, the challenge for the industry still remains that such a design, if available with proper technical backing, should be made available in the public domain in literature, portraying actual light distribution with sufficiently uniform broadening over a very broad angle in technical terms. At the end of “SSL Beyond Efficacy” session, I commented that LED’s inherent Lambertian profile is what makes it so difficult to spread the light over a very broad angle in a uniform fashion; the speaker, Mark Dyble agreed and replied with gratitude for bringing up such a crucial topic and explanation.

While I listened to Brandston’s wisdom on lighting, I noticed some annoying glare just behind the stage where he sat with Chip Israel. I immediately spotted that the glare was coming from an LED luminaire from a booth behind the stage. I took a photo to capture the scene; after some time, the luminaire was turned off and I took another photo. The stark contrast can be seen in the photos of figures 4 and 5.

Figure 4 (left):
A glary LED light just behind the stage (circled) where Howard Brandston (left) and Chip Israel (right) sit

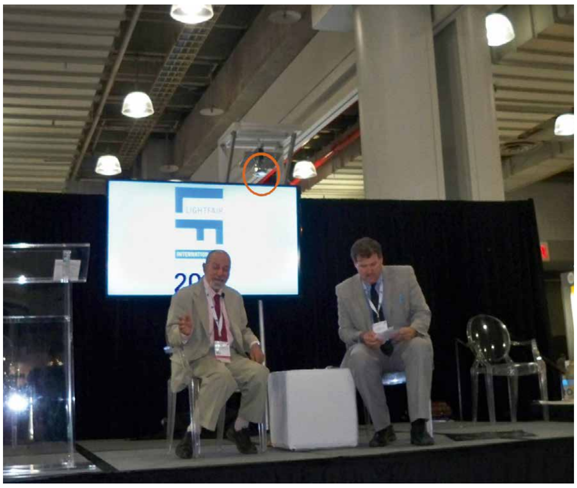


Figure 5 (right):
The LED light behind the stage seen in figure 4 is now turned off, making the surroundings glare free

Figure 6 (left):
Several LED luminaires showing glare where the traditional luminaires in the ceiling are showing normal luminance and illumination.

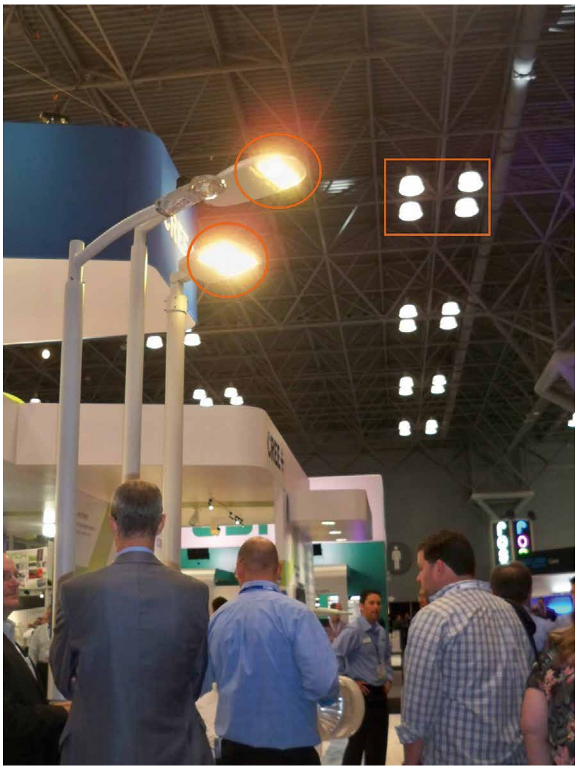


Figure 7 (right):
LED outdoor luminaire with strong glare while the traditional metal halide luminaires above show no glare

Although such photographs capture these blatant scenarios to some degree, the camera does not portray the actual differences in intensity levels that we perceive in real-time, which are far more irritating.

As mentioned previously, it is not always valid to show a comparison of different lamps by taking photos of illuminated lamps, especially on separate occasions. The reason is that the camera has its own flash that adds to illumination and we cannot judge the intensity levels properly from photos. (Although in the absence of flash, accurate luminance measurements can be made via goniometric methods, they must be done in a setting where the camera to lamp distances need to be appropriate and very careful calibrations need to be performed - all of which are extremely time and space consuming tasks. Further, measuring two or more luminaires at the same time is far more difficult than one and therefore quantitative luminance measurement comparisons of numerous lamps from the same camera set up is extremely rare.) However, taking photos of lamps with extreme luminance where other lamps with far less or normal luminance levels are also present, some valid qualitative comparison judgements can still be made with regards to whether certain luminance is, in fact, too high. This is demonstrated in the following photos (Figures 6 and 7) where LED luminaires are showing extreme glare in comparison to other traditional lamps in the surroundings. Although some manufacturers use translucent shields to avoid glare, it comes at the cost of lowering efficacy. Proper glare reduction may come when some suitable secondary optics is truly able to substantially change LED's inherent Lambertian light distribution. This is a real challenge for the LED lighting industry that lies ahead.

About Smart Lighting

The LED challenges were hardly discussed at Lightfair 2015 and it would be safe to say that many concluded this year's show was really about smart LED lighting, which is poised to become mainstream. Although the smart LED lighting concepts have been discussed in the R&D and academic arena for several years, the major companies only delved into it more recently. It is now a dominant sales tone for LED lighting in the commercial world and traditional lighting is pressured to keep up by utilizing lighting control to any degree possible. Of course lighting control for traditional lighting has been around for a long time and Zigbee, DMX, DALI and other technologies have supported automatic dimming, on-off, and other control features in traditional lamps. LED lamps are further controllable in that they can be electronically tuned to produce different CCT – a unique feature that is not possible with other lamp technologies. In fact, it is argued that smart LED lighting should become the vital part of Internet of Things (IoT) systems because LEDs are penetrating the mainstream market rapidly; in addition, along with their unique light control capabilities, they are a natural platform for integrating control drivers for light management as well as for sensors to implement surveillance, environmental and maintenance supervisions.

Numerous companies I talked with at the show elaborated on these advantages. Charles Knuffke from WattStopper explained how their lighting control systems are connected via both wired and wireless systems depending on an overall management network that includes both backbone and distribution connections. WattStopper has been one of the major lighting control companies for a very long time and therefore is very experienced with network efficiency that is crucial to saving power. Although they provide smart lighting systems for indoor and outdoor applications suitable for both LED and traditional luminaires, their core business lies in offering a complete management system that is efficient and user-friendly. When I asked Mr. Knuffke whether LED lighting systems have an edge over traditional counterparts, he said the outdoor lighting applications, in particular, has an issue with not having enough light in between LED luminaires. Not surprisingly, it is the light distribution problem I discussed earlier in figures 3(a) and (b).

Terralux's Anthony McDougle and Matthew Sallee explained their high-performance electronic drivers and controllers that can implement smart lighting as well as smart systems to control and monitor lighting and even such environmental factors as smoke or toxic fume detection.

Rick Walker from CSR, a Bluetooth and GPS electronic chip company that was announced to be bought by Qualcomm in October 2014, explained how their wireless systems and applications can be utilized by residents to control their LED lamps from anywhere in the house to suit their needs.

Samsung held their press conference the day before the show opened for exhibitors and smart lighting was at their center stage. When a press representative stressed that Samsung is late in the smart lighting game, their recently appointed EVP and COO, Dr. Jacob Tarn replied that it is only "8 AM for smart lighting" and there will be plenty more to look forward to.

All of these companies understood when we discussed LED light distribution challenges and they look forward to future solutions that will make solid-state lighting more suitable for large area illumination. In my personal discussion with Samsung's Dr. Tarn, he seemed agreeable to LEDs being glary and having light distribution shortcomings. He explained that LEDs can afford to be wasteful because lumens are coming too cheaply; in other words the scenario is similar to when fiber bandwidth was too cheap as I discussed previously!

Perhaps it is true that lumens are too cheap nowadays. It would explain why some companies are using lasers for car headlamps and other lighting applications. This is another sign that too much attention is given to generating lumens at high efficiency and not enough attention is given to the light distribution challenges that come with LEDs and lasers. The confusion has gone as far as coining the term "white lasers" which is, of course, silly and contradictory. When someone asked Dr. Shuji Nakamura (2104 Nobel Prize Winner in Physics) after his Keynote Luncheon Speech whether white lasers can be coherent, he politely answered that after phosphor conversion, only spontaneous emission property is found in the light beam!

How We Can Make LED Lighting Adoption Last

Although smart lighting benefits are compelling, they are still only secondary benefits behind the primary or the typical lighting features, which are uniform, balanced and glare-free omnidirectional light distribution with high-quality color characteristics. These primary features are the ones that should define "human-centric" lighting. But because lighting and illumination are both subjective, the practice of wrapping "bells and whistles" around the premature LED lamps has proven an effective sales method thus far. Another such secondary aspect is focusing on new ways to quantify CRI as described in the IES technical memorandum TM-30. Cree, at their booth, and Marc Dyble from Osram Opto Semiconductors in his presentation, "Beyond SSL Efficacy" elaborated on the different CRI appearances based on TM-30 proposals. While this new description and implementation can provide another type of illumination criteria based on subjectivity, in my view, it is still a lesser addition compared to fully defining the primary features. In spite of the dramatic price reduction that took place for LED lamps over the last few years, their manufacturing and materials are still very costly and it would be wise to not burn additional billions of dollars toward undesirable lamps that stand to be discarded in the not too distant future.

Achieving the primary light qualities from solid-state lighting devices requires that the manufacturers understand the fundamentals of light and lighting science. Despite remarkable LED technology improvements and product developments, achieving the primary lighting features is conspicuously difficult in LED lamps. Nevertheless, many profit-seeking manufacturers manage to sell premature products with various secondary functionalities that shadow the basic light qualities because proper LED lighting standards are still absent.

To produce more human-centric LED lamps that sustain the primary lighting qualities for general illumination applications, the light-emitting surface must be curved so that light emissions are less direct and glary. Manufacturers could accomplish this by appropriately designing secondary, optical elements such as waveguides and light pipes. An entire LED luminaire incorporating such a design that is also optimized for thermal management are important aspects of a complete, high-quality and dependable light source. Breakthrough technologies in polymers and silicones from companies such as Dow Corning will likely play a key role in providing the necessary secondary optical components for developing such LED luminaires at low cost. Until such general-purpose LED lamps are manufactured, certain architectural and accent lighting from Hisun, Bulbrite (King of nostalgic collection), Global Lighting and others are nevertheless pleasing and marketable.

While it was encouraging to hear the long-time professionals from the lighting industry speak of some wisdom in defining quality and beneficial lighting, they did not provide any specifications that can be turned into standards. Standards with suitable metrics and specified quantities for lighting parameters are needed to affect real change in the LED and optoelectronics industry so that they can produce the right type of LED lighting products. It would be rather difficult to adopt the wisdom or "seeing" abilities of those like Howard Brandston to shape the LED lighting industry. Although an average person today is unable to judge lighting quality or see light like him, the lighting industry will sooner or later gravitate towards defining the characteristics that have made certain types of artificial lighting beautiful, comfortable, and that mimic nature for over 100 years. Many of these lighting characteristics, in particular those relating to spatial light distribution and not color properties, have not been established in literature yet. But the industry will need to do so as the participants understand light from a scientific and artistic point of view and can establish standards based on such.

Despite some gaps that remain in the industry, which include understanding glare and light distribution issues, adopting the appropriate standards and finding low-cost solutions for high-quality LED lamps - I remain hopeful that the lighting industry will find solutions and utilize all strengths to make LED lighting more comfortable, aesthetic, and mendable to suit all of our illumination needs including optimal consumption regarding circadian rhythmic and other photobiological phenomena while providing substantial energy savings. ■

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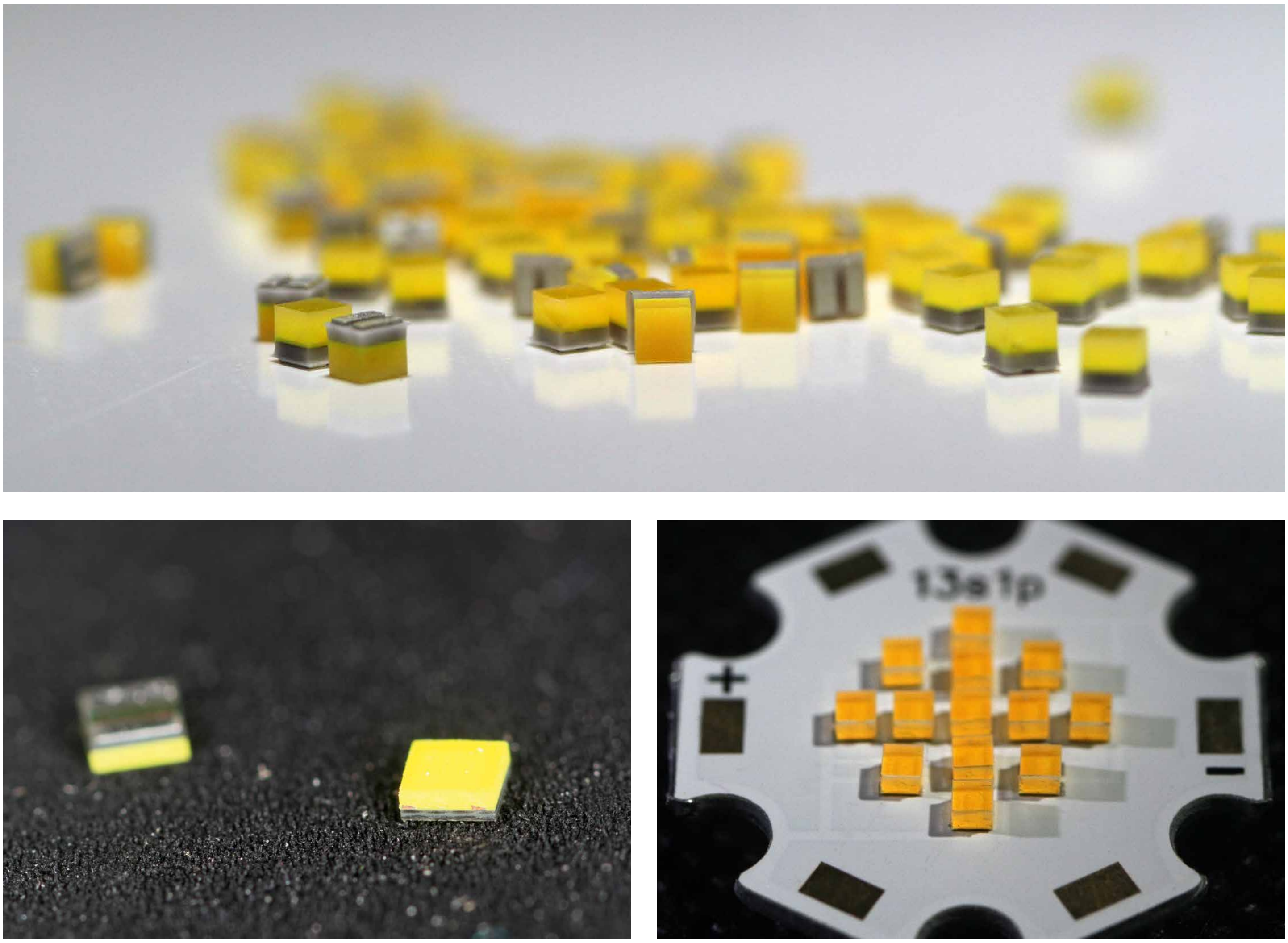
GILE 2015 Trends – LED Chips, LED Packages, Drivers & Controls

This year, to celebrate its 20th anniversary, the GILE event was bigger than ever. Arno Grabher-Meyer, Editor-in-Chief at LED professional was invited to attend and report on the products and trends seen at this outstanding Asian platform. Everything that is needed in the LED lighting business, from LED components to luminaires, from raw materials to testing and manufacturing equipment is provided here. In addition to the exhibition, there was also an extensive lecture program.

While travelling to one of the most important exhibitions in the world, I had time to think about what has been discussed during the past few weeks and months regarding light. Things like the quality of light, glare, the future of LED lighting, or even what one could expect from this exhibition. Like many other cities in China, Guangzhou has its share of skyscrapers, busy people, traffic jams and blinking lights all around. But the thing that makes it different from the cities in Europe is the fact that all the flashing lights are LEDs. Is this a positive attribute? Yes, and no. Yes, because it saves energy. No, because it is too bright and glary. The night is fading into day but the lights are not as nice as sunlight. For a European that is used to a softer and warmer ambiance, this light feels cold and technical. On the other hand, I realize that this is another country with a completely different culture and the reason I came here is because GILE, the biggest lighting fair in Asia, organized by Messe Frankfurt, is celebrating its 20th anniversary and I'm curious to learn what is going on and what is new in the Chinese lighting business.

At the opening ceremony, Stephan Buurma, Member of the Extended Board of Management at Messe Frankfurt GmbH emphasized the relevance of the new era that was introduced with LED lighting. He mentioned HCL as well as IoT, which are the results of this development and drivers for the future of lighting.

Opening ceremony of the 20th Guangzhou International Lighting Exhibition 2015



Flip chip LEDs and Chip Scale Packages (CSPs) clearly belong to the upcoming trends. Though currently not widely applied due to handling and infrastructural issues, LED producers and packagers like Kinglight, Honglitronic and Epistar are convinced that this technology will become mainstream within the next two years

Hall 10.2 - Brand Name Hall for Chips and Packages

The so-called brand name halls at GILE are a playground for most of the leading manufacturers from all continents and countries. The visitor gets a perfect overview of the LED lighting ecosystem in these halls and the exhibitors, all of whom strive to show their latest innovations, represent the who's who of the LED and LED module business. Here is where the visitor can draw conclusions regarding the future of LED lighting by regarding the trends that the big players are following. I would like to emphasize here that the big players are, by far, not just the well-known brands from the western hemisphere. There are also many Asian, and especially Chinese companies that demonstrate innovative strength.

China's leading companies

Since about 80% of the more than 2,600 exhibitors were domestic Chinese companies; many of them chip manufacturers and packaging companies it won't be possible to give a complete overview here. Likewise, trying to figure out which ones will challenge the leading overseas companies with their innovative power in the near future is a task similar to finding a needle in a haystack. Of course there are the well-established brands from which we can expect some challenges but there are also many others, not much smaller, maybe not less innovative, but as yet, mainly focusing on the domestic market.

The vertical integration of all these companies ranges from pure chip manufacturers to full system providers that cover all manufacturing steps from chip manufacturing to packaging, lamps and luminaires, and sometimes even to drivers and controls. The latter sometimes make a profit with their finished products. Selling basic LED chips and packages is then more like a kind of extra. The following presentation of Chinese companies and their offerings gives an overview of the large variety of strategies and capabilities.

Companies like HC SemiTek or Shenzhen Xu Yu Optoelectronics that are specialized chip makers or packagers seem to focus more on a solid and proven technology and workmanship on all levels of the production chain than in developing a sophisticated and groundbreaking new chip technology or packaging technology. This is basically also true for the wider, vertically integrated companies Shenzhen Lepower Opto or Sunpu-Opto Semiconductor. Having said that, Sunpu-Opto Semiconductor shows remarkable innovative strength in respect to applications. AC COBs are one thing, but human centric lighting with a combination of white and red LEDs, CRI 95+ and a narrow CCT stepping, and in particular Smart COBs, clearly demonstrate the desire for technical leadership and admission in the group of high quality lighting providers.

Refond showed improved versions and amendments to their wide product portfolio; namely their performance and cost competitive high quality High Voltage (HV), High Power (HP), and COB LEDs.

Shenzhen Jingtai, also known as Kinglight, offers color and white LEDs for different applications whereas the innovation focus at the fair was on a patented ultra-compact black RGB LED QFD package to improve the contrast and pitch of HD indoor displays. They also introduced a 220 VAC module.

Shineone Beijing Technology provides their own high CRI white light for shop lighting applications to improve whites. They combine UV-A LEDs with a wavelength close to blue LEDs within one package to generate phosphor converted white light. The green to red spectrum is mainly generated by the excitation of the phosphor by the blue light, while the shorter wavelength of the purple-UV light improves the appearance of white clothes; an effect similar to that of Soraa's unique GaN-on-GaN LEDs based white light.

Honglitronic featured their latest Chip Scale Package LEDs of the 1515 series that are capable of being driven at up to 6 watts, making this tiny device powerful enough to design a 50 W MR16 LED replacement lamp. The CSP technology is also used for COB modules to produce high density CSP-on-COBs. Due to the large amount of requests for filament lamp modules another focus was on these improved products that now provide a 360° light emission angle to better mimic incandescent light bulbs. As one would expect, Honglitronic also provides highly efficient AC-LED modules with a high power factor and low THD. The company also extended its activities in the non-visible LED business. With their full range of UV LEDs from UV-A to UV-C, they are prepared to satisfy the complete bandwidth of UV applications.

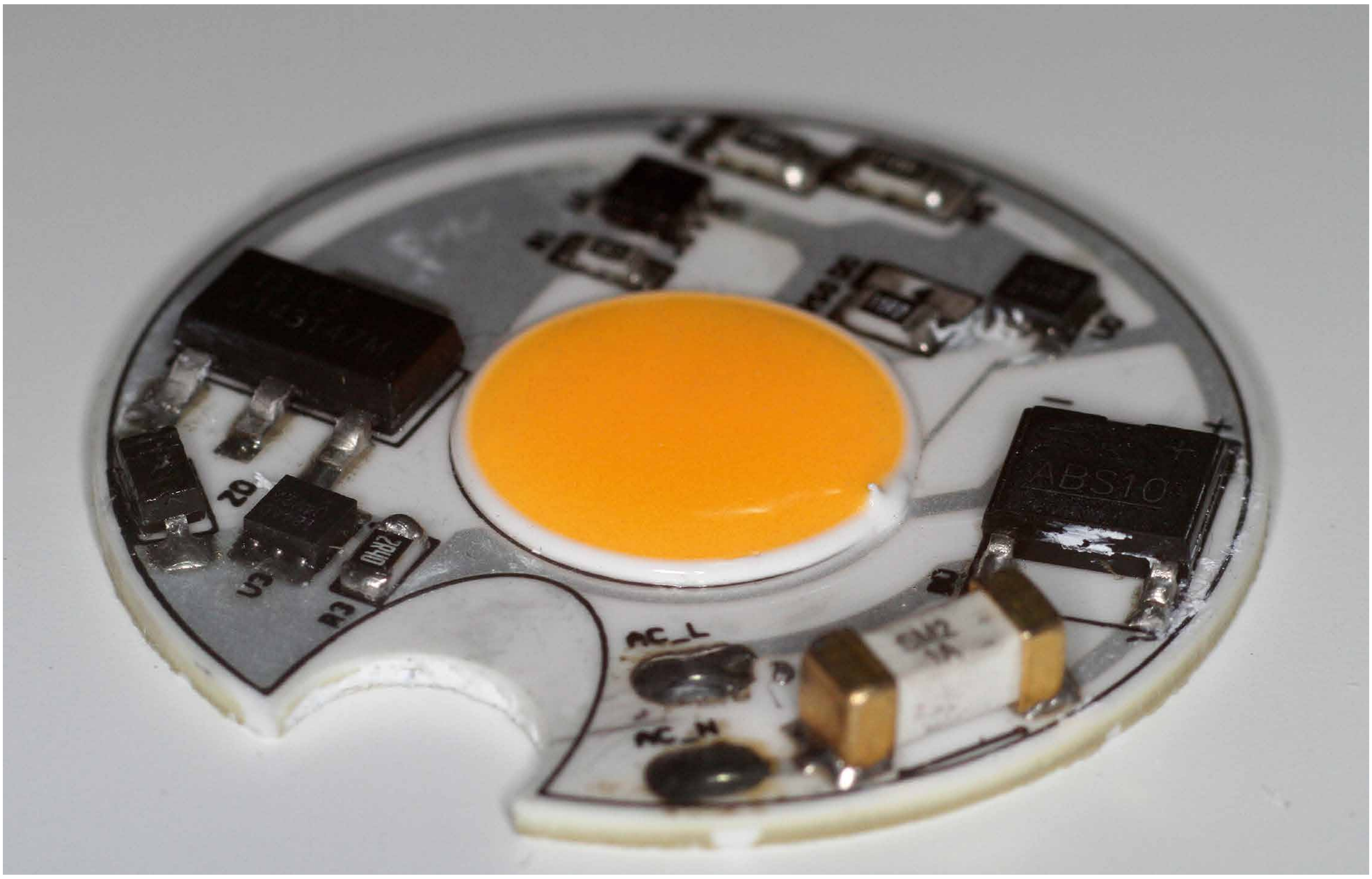
Jiangxi Lattice Bright, Jiangxi Lantian Weiguang, Getian Group, and APT Electronics also stand for innovation with a broad product portfolio, offering HV LEDs, AC LED modules, Flip-Chip LEDs and FC-CSP LEDs as well as FC COBs, and vertical LEDs.

Other Asian and Overseas Companies

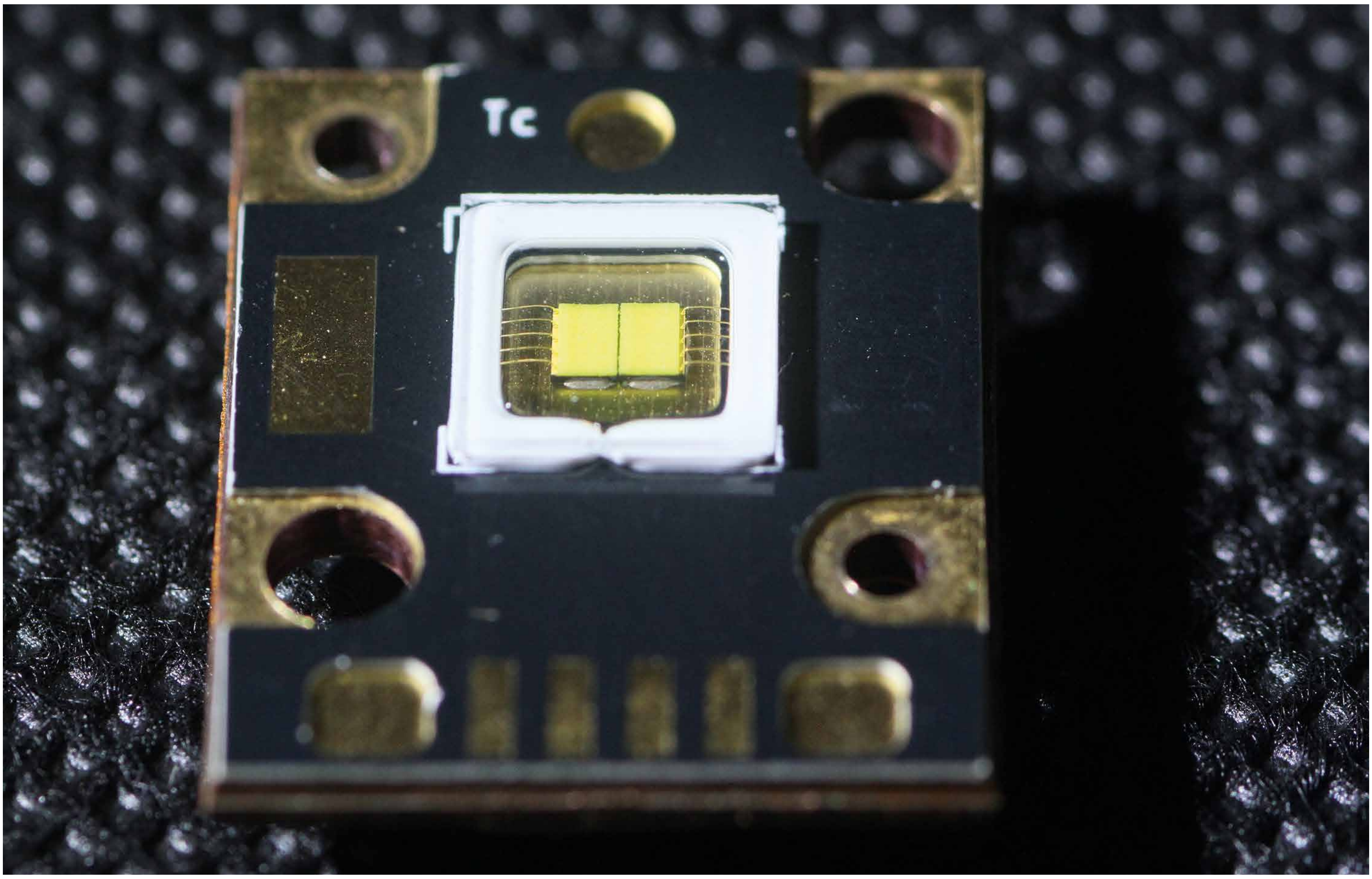
While big names like Nichia, Philips and Osram were missing, and Cree was in the "Brand Name Hall of Outdoor Lighting", the other renowned brands crowded together in Hall 10.2.

Taiwan's big boys, Epistar, Everlight, Epileds, Edison Opto, Lextar, Prolight Opto, as well as some smaller LED and packaging companies presented their latest products. Some of them used the fair to introduce new products or improved versions. They demonstrated all together their mature versions of CSP and FCCSP LEDs, FCCSP on COB, Driver On Board (DOB), Driver on COB (DCOB). When asked what the future trends were, they predicted, without a release date, higher integration levels like sensors and controls interfaces on board for their products. Lucy Chen from Edison Opto confirmed the relevance of higher integration. She explained, "Our company sees several reasons to increase the level of integration in COB and modules, and we have already started to realize that in several new products. One reason is certainly simplification and ease of application without compromising quality aspects. Another is improved functionality." The latest products shown were AC COBs and modules with reduced flicker, DOB modules with integrated optics, improved primary optics. On the other hand, in order to satisfy other requirements, like wider beam angles and lower costs, Edison offers a CSP package. Epistar, as a declared chip manufacturer has less options to add features. Their focus is on the diversification of epitaxial growth and substrates to satisfy different quality and cost aspects as well as their clients' applications. The latest example does not concern general lighting. It is their LED for projector designs. The product is a vertical LED that has a narrower beam angle than conventional LEDs. This simplifies optical design and improves overall system efficiency. In order to lessen the repercussions of the green gap, they designed a green PC LED and added a filter to narrow spectral width resulting in over 50% better green efficiency.

Companies from other countries, like Samsung and Lumileds, featured small LES COBs or HD LEDs. In addition, Citizen presented an extremely high powered COB, and AC LEDs. AC LEDs specialist, Seoul Semiconductor, improved the Acrich3 by adding capacitors that reduce flicker and result in a better power factor and less THD. A new generation of CSP and multi-junction HV LEDs complete their highlights. Luminus Devices emphasized something different. Small LES products and improved CRI and the introduction of GAI to qualify color gamut capabilities are their prominent features, and, of course, CSP LEDs. CSP LEDs are the central focus of Lumens. Their unique silver-free reflection layer design, of which they claim to have the industry's best reflectivity and lowest degradation, is the basis of their technology. But with their experience in BLU manufacturing, they are capable of customization and the integration of sensors on a module level.



Following Driver-on-Board (DOB), Driver-on-COB (Everlight DCOB, above) as well as customization (Epistar projection LED package, below) for special and niche applications are trends that allow many companies to differentiate and avoid the escalating price-war



Tridonic presented both their high-end module lines dedicated to the European market and cost-optimized products for China. Alfred Felder, CEO of Tridonic, explained their strategy:
"Tridonic has seen that many overseas manufacturers tried to enter the Chinese market with just slightly modified products that did not fit the requirements well enough. These companies were not successful. Therefore, Tridonic analyzed the requirements of the Chinese market and designed products especially for this market. We believe that this is the way that will lead to success." The differences between these versions are significant. For Europe and the Americas, smaller steps in CCT and higher CRI as well as maximal efficiency are available, while for the Chinese market standard 80+ CRI, good efficiency and a limited number of different CRI versions seem to be sufficient. Also the choice of materials or LED type may differ for a similar application. In addition to their modules Tridonic also presented their electronics from basic to sophisticated drivers and controls.

Bridgelux recently named Andy Man their new Senior Vice President, Asia Business. Andy gave LED professional an exclusive interview in which he explained Bridgelux's view and strategy for the near future. Although different in some details from the company history, his general statements also reflect many aspects of the position that other big players in this business expressed in discussions. Their strategies are also in accordance with the statements and findings heard in different sessions throughout the day. The discussion was an outline of innovative trends and future perspectives for LED chip manufacturers and packagers.

Historically, Bridgelux started with chip manufacturing, but very soon recognized the advantages of packaging themselves. They were one of the first companies to offer COBs, and later modules. Not very long time ago they also entered the SMT business and followed that with CSP LEDs. When addressing the issues of CSP, like ESD handling, placing accuracy, etc., Andy emphasized that the company has thoroughly investigated the different package types and the schedule of the products is always timed strictly according to the recognized market requirements. That means that Bridgelux releases products very strategically, waiting for the moment when they think that the market and their clients are ready. He said, "The LED market has been changing fast and will change very fast in the future. There are many new players coming. That will lead to a consolidation and only the innovators will survive in the end. Key factors will be high quality, reliability, price performance, and very important support."

Observations from Hall 10.2

As expected, there wasn't one single big trend, but rather, several, important smaller ones. Those that expected revolutionary new trends were probably disappointed since most of the trends were indicated through formerly presented or announced technologies and prototypes. The early adopters and, in some cases, wide spread adoption, confirmed that the pioneering companies were right. Several of these trends are very obvious while others are not. Some of the major trends are HD COB LEDs, CSP LEDs, HCL, Direct-AC LEDs and modules, DOB and DCOB modules, and even higher integration levels to provide IoT connectivity. In addition to these technology trends some tendencies became visible that are not primarily based on propagated new technologies. These are all the trends concerning better light quality. An increasing number of manufacturers from many different countries are paying attention to better color rendering, not necessarily based on CRI, but some other metrics or simply the defined requirements of the user.

The Other Halls – Drivers, Controls, Testing and Manufacturing

In these halls, many of the established international material specialists, like ALMECO, ALANOD, Henkel, Shin Etsu, Dow Corning, Trinseo, DMS Engineering Plastics, Bergquist and Rusalox or testing and manufacturing component and equipment providers like Instrument Systems, Everfine, Konika Minolta, Stucchi, LPKF, BAG, BJB, and WAGO filled the halls with an overwhelming number of local companies. With Infineon, On Semiconductor, Macroblock, Power Integrations and Dialog Semiconductor there seemed to be more driver IC manufacturers from overseas present than driver and supply module manufacturers. While all these international brands are very well known, out of the many Chinese companies only a small exemplary number with their product highlights can be present in this report. Most of these companies are driver and supply or driver IC manufacturers with only a few with overseas offices or distribution. Even so, some very interesting products were displayed.

Everfine, with all its latest inventions should be mentioned here to represent all the Chinese testing equipment manufacturers and service providers. To improve testing speed, quality and repeatability for lamps and small luminaires, they introduced fully automated systems for performance and electrical testing as well as aging testing.

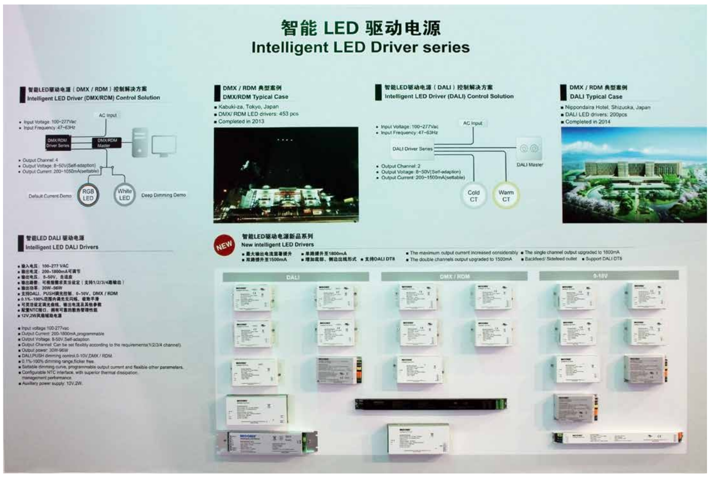
In the end, though, the driver and controls IC and module manufacturers were of the greatest interest. Their activities show how evolved smart lighting really is and how this topic is seen in China and for the mass market.

Maxic Technology offers AC/DC as well as DC/DC drivers. They currently still focus on standard features like protection features and sometimes integrate HV MOSFETs in their driver ICs, which offer quite good PFC,

Light quality is a focus for many companies. Features for smart and human centric lighting like color tuning, products for "high punch" narrow beam angle, or AC-LED modules with reduced flicker and good dimming capabilities were referred to as upcoming trends not only by companies like Bridgelux, Luminus Devices or Seoul Semiconductor, but also by local Chinese companies like Sunpo or LTWG

THD performance and efficiency. Another IC manufacturer, ChipLink, clearly stated that their products are designed for the internal Chinese market. On the contrary, On-Bright Electronics strives to extend their business beyond the Chinese borders and also recognize the controls business as a relevant part of their future. A wireless controls system is currently being developed in cooperation with one client and should be available on the market soon. A demonstrator was presented at the fair.

The much bigger group of supply and driver module manufacturers was even more heterogeneous. A vast number of smaller manufacturers offered standard products and a few advanced products. However, there were a number of companies that highlighted more advanced products in a more international style. Most of those manufacturers emphasized that their products have UL, TÜV, DEKRA, ENEC or other relevant safety certifications for



LED drivers that are compatible with numerous dimming controls methods or that are available for all relevant methods, as well as drivers that are compatible with smart controls like DALI or DMX are standard for China's top players like Easeic and Moons. Wireless connectivity and IoT is already a topic for China's IC and module manufacturers like Maxic

almost any country worldwide. Many of the companies focused on special market segments; mainly outdoor drivers. Their reasons and arguments are manifold. One can hear any argument from "quality requirements that not any manufacturer can provide, and therefore lower price pressure" to simply market issues as "outdoor LED lighting is booming", especially in China. Outdoor lighting is also on the forefront of smart lighting. Smart features, like central time-controlled dimming of any single streetlight, already seem to be a basic requirement. Some manufacturers just provide the supplies and offer a smart controls solution in cooperation with specialized controls manufacturers. Others are working on their own controls solutions including the software, to provide all in one. Currently following this strategy are MOSO Power Supply Technologies, Pairui Group, and Inventronics. Shanghai Moons Automation, Shenzhen Ledfriend and Easic offer some controls options as well as intelligent solutions for indoor lighting, whereas the extent varies from simply providing a DALI interface to wireless solutions with gateways for different protocols. Many other companies, like ADPower Technology, Zhongshan Gocolor Lighting Electronics, Ningbo Snappy Optoelectronics or Dongguan Linkuan Semiconductor Lighting mainly offer standard solutions, non-dimming, 1-10 V dimming or TRIAC dimming.

Impressions of drivers and controls

Visits to several driver and controls manufacturers as well as statements by representatives from a number of companies led me to the conclusion that IoT is important, but certainly not big business. There are still too many uncertainties. The arguments against it are that there is no accepted standard, there aren't enough requests for it, it's too expensive and it isn't mature enough. The Connected Lighting

Alliance, who exhibited some of their members' latest developments, recognizes the importance of IoT and is taking steps to help it gain the momentum it needs.

The Concurrent Program

With over 120 lectures with topics ranging from business to policies, and from solid-state lighting technology to lighting design, there was something of interest for everyone. As with the exhibition, because of the large number of lectures I can only talk about a few.

Epistar General Manager, Mingjun Zhou, was introduced as the representative of the industry. He pointed out that there are two different "worlds" in this industry, the one is the world of technology, and the other is the application world. He pointed out that these two worlds need to meet and match each other. He also talked about upcoming changes. These would be the expiration of basic IP and collapsing prices resulting in consolidation mainly through the merger of companies. This will be the result of many companies having to face the question of how to generate value. He feels that the solution would be to provide quality, smart lighting and adding value with IoT. He sees this situation equally as a challenge and an opportunity. He emphasized the opportunity to come to a stable and healthy business structure.

In his talk "Global LED Market Developing Trends in 2015", Roger Chu from LEDinside outlined a very similar picture. Over the past few years he has seen many weaker patents being filed, a lot of cross licensing efforts and attempts to make money before they are invalidated or expired. Regarding technology, he sees a trend from SMD to COB, which has advantages in heat transfer and offers more opportunities to differentiate. Due to the lack of standardization he only sees smart lighting and IoT as business in the long term. This means that lighting will act as a carrier for other applications, for instance, by integrating sensors. He expects Apple and Google, but also some Chinese companies like Meizu, Alibaba or XiaoMi to come into the game and predicts that intelligent lighting will not enter the residential market in a big style before 2019.

Honglitronic's General Manager, Lining Lei, talked about flip-chip technology. He explained the path from flip chip LEDs to Chip Scale Packages. He emphasized that in the meantime, technology has become mature and the technology supports the logical law of technical evolution from a complex to a simpler system. Mr. Lei emphasized that FC LED packaging is still a challenge in regards to accuracy and different approaches lead to products with different properties. FC LEDs with a substrate are, for instance, less directional than their counterparts without a substrate. From a business perspective, he expects the combination of CSP and COB to be an opportunity for his company to extend market shares.

Osram's Marketing Manager for Asia, Vincent Wu presented their approach for reduced packages and LED component dimensions. He compared different technologies and showed pros and cons regarding different parameters. The Osram concept PureLED, product name Duris S2, is based on a standard LED in a minimized package. The LED is not intended as a high-power product but rather as a mid-power product with a good balance between cost and handling.

Epistar, well known for its LED chip manufacturing skills, gave a lecture on "GaN Power Devices for LED Lighting", held by their Vice-President of R&D, Dr. Carson Hsieh. This lecture about the growth of GaN Power devices grown on Si, demonstrated astounding research activities carried out by Epistar. Their prototypes already demonstrate very interesting performance and future perspectives. Compared to a conventional buck design, power can be held relatively constant over a wider input voltage range with much better efficiency. Two of the advantages are that THD is lower and PF is much better. In combination with HV LEDs, a significant improvement in overall system efficiency and miniaturization is possible. Currently, still manufactured as a standard IC, one could imagine that the next step might be a monolithic design.

Final Thoughts

If I was asked to sum up those four exhausting, but extremely interesting days in one word it would very likely be something like "bewildering". In short, there were no groundbreaking new technologies and trends demonstrated. Some of the true trends demonstrated were miniaturization and simplification on the one side, represented by CSP and AC LED technology and on the other side, improved light quality and HCL, and smart lighting including IoT. These are emphasized through the broad adoption of many international, but especially leading Chinese companies. It seems that the component manufacturers are ready to provide the tools for the future of lighting.

However, all of this is based on visits to component manufacturers and consequently discussed from a component level frame of mind. Coming back to the thoughts in the introduction to this article about poor light quality, gallery lights and inadequate illumination levels - this is very likely caused by the elation for new toys, LEDs and a young generation of products. Hopefully, the luminaire manufacturers as well as planners will be able to cope with these new opportunities and tools, and will not forget the central topic - light and the quality of light. In that case the future will bring interesting and valuable new products to the end-user. Probably the next opportunity to reassess the result will be at LpS 2015 in Bregenz. ■

LED Lighting Taiwan – Strong Focus on UV and IR

This year, LED Lighting Taiwan, as part of the Photonics Festival Taiwan, focused on UV and IR LEDs and applications: At first glance this is a topic that doesn't really fit the focus of LED professional. However, already having been in Guangzhou the week before, it was a great opportunity for Arno Grabher-Meyer from LED professional to meet the Taiwanese LED manufacturers at LED Lighting Taiwan and to learn about their reasons for increasing their activities in these fields.

LED Lighting Taiwan is a part of PIDA's Photonic Festival. LEDs go beyond general lighting and visible light; in fact the definition of visible light is only valid for human vision. Many animals, birds and insects use other wavelength ranges to see. Even camera sensors have a different type of "vision". Furthermore, and especially in the year of light, it would be interesting to find out what LEDs and light can do for our lives and where and how these things are applied. While the technology of UV LEDs is basically similar to that of visible, or more precisely blue LEDs, it might also help to understand this technology better. Since most companies provide both visible and invisible light as well as other products they will be covered in this overview.

About IR LEDs at the Show

From a technical point of view, IR LEDs are not as challenging as UV LEDs. However, the applications for IR LEDS are better known then UV LEDs. While they were promoted and displayed at the show it seemed more like these products were considered add-ons with the main focus in research and development as well as business models being on UV. There might be one or two exceptions further down the line for IR, but probably not much more.

The Vice-President of Taiwan, Wu Den-yih led the inauguration ceremony of the Photonics Festival and visited the exhibition to gather information about latest developments. Here he is talking with LiteOn's Group CEO, Warren Chen

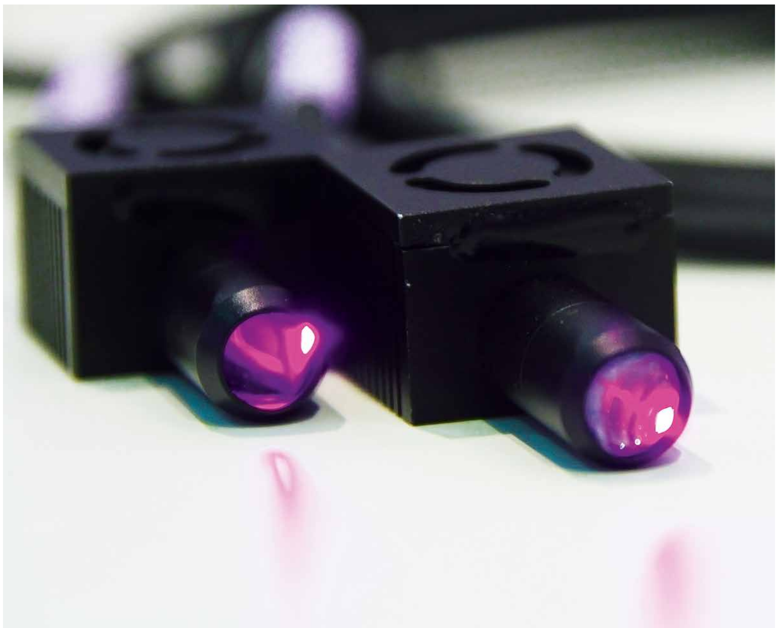
UV Light and Its Applications

UV light is a very wide and open term as UV is classified in UV-A, UV-B and UV-C with very different characteristics and applications. While UV-A of low intensity and for a limited time can more or less be recognized as non-critical for human health, both other categories, even in a relatively low dose and in a short time, can damage tissues or DNA.

UV-A, with a wavelength between 315 and 400 nm, has many different applications. UV-A in the longest wavelength range close to visible light, often referred to as "black light", can damage delicate paintings on the one hand, but on the other hand can be used to make white clothes look brighter and whiter. This UV-A wavelength can also be used to generate white light by multi-phosphor conversion. While being less efficient compared to white light generation with blue LEDs, the advantages in the spectral light quality are not deniable. Therefore, possible applications for UV-A can be found in general lighting. In addition, it can be used for curing different plastic compounds from nail lacquer to dental fillings and tanning or photolithography, which are all important applications for business.

UV-B covers the smallest range from 280 to 315 nm and therefore has less, but nevertheless, very important applications. These are mainly in the medical and bio-medical fields like protein analysis and phototherapy.

UV-C (200-280 nm) is useful for disinfection and purification as well as sensing. It would certainly be interesting to learn which application the different manufacturers are targeting and to know if they see new, upcoming applications.



IR LEDs and UV LEDs have a number of very important applications in our daily lives. While IR LEDs are indispensable components of surveillance cameras, UV LEDs are used for the curing of plastics and other tasks

UV LED Technology Basics

LEDs are basically so-called III-V semiconductors, whereas the numbers define the groups of the periodic system of elements that are used. UV LEDs basically belong to the same LED family as blue or green LEDs. They are GaN based and therefore the production process is quite similar. The LED color is defined by the amount and relation between the three elements of group III, Al (Aluminum), Ga (Gallium), In (Indium). The group V element, N (Nitrogen), always stays the same.

For the shortest wavelength, UV LEDs, Al mostly replaces the Ga element, whereas in deep green LEDs, Ga is almost completely replaced by the element In. In both cases the efficiency of the LEDs is dramatically reduced. In the visible light range, this phenomenon is known as the green gap. In UV the problem is even bigger.

The reasons for this lower efficiency are manifold, but mainly due to dislocations in the lattice structure. Just to give you an idea: While the latest blue LEDs reach an External Quantum Efficiency (EQE) of up to

80%, the latest published laboratory EQE record for UV LEDs with 265 nm is 6.3% [1]. At approx. 300 nm, EQE is at 10%. UV-A light of 405 nm has an EQE of approx. 65%. But this is not the only challenge of manufacturing UV LED products even if it is the cause of some.

Especially in UV-C and UV-B LEDs, one clear challenge is the extremely high thermal load and stress. In many applications, high intensities are required. High power LEDs with such a low EQE dissipates a lot of energy as heat. The package needs to have a high thermal conductivity to guarantee safe operation, reliability and long lifetime. There are high requirements on the packaging material in any case. It needs to be transparent or reflective for UV light, which is not the case for any commonly used material. It should also resist UV to avoid yellowing of the transparent primary lenses and white reflectors. Otherwise degradation and efficiency decay would be the consequences. High power LEDs are therefore usually COBs and very often ceramic COBs.

Manufacturers of UV and IR Products

Despite the fact that PIDA proclaimed this year's LED Lighting Taiwan to be an UV and IR LED Exhibition, I wanted to know what the other reasons for the LED manufacturers to increasingly promote and market these types of LEDs in 2015 were. I have noticed that not only those exhibiting at the fair, but also other manufacturers have been announcing new UV LEDs throughout the year. However, no dramatic improvements in efficiency or other technical parameters have been demonstrated up until now and most of these product applications are already known.

So, what is the reason? When I asked representatives of various companies their replies varied from complete silence to answers of questionable plausibility. But one explanation was convincing: The price pressure on visible LEDs through Chinese manufacturers has become so high that the profit margins in this sector have been dramatically lowered. Therefore, companies that have the capabilities and technical know-how aim to expand into other business fields even if these are specialized niche markets. Originally, just three companies had a clear lead in this field, dominating for a long time through better performance and better quality. Meanwhile, this advantage has been reduced to almost zero. While UV LEDs are mostly required in industrial applications with quite high demands, and most Chinese manufacturers cannot satisfy these requirements, price pressure is relatively low. Other qualities like customization of power, wavelength or radiation angle are, by far, more important. Hence, the time to promote these products has come for the Taiwanese manufacturers, Optotech, Epistar, Everlight, LiteOn, and TSLC.

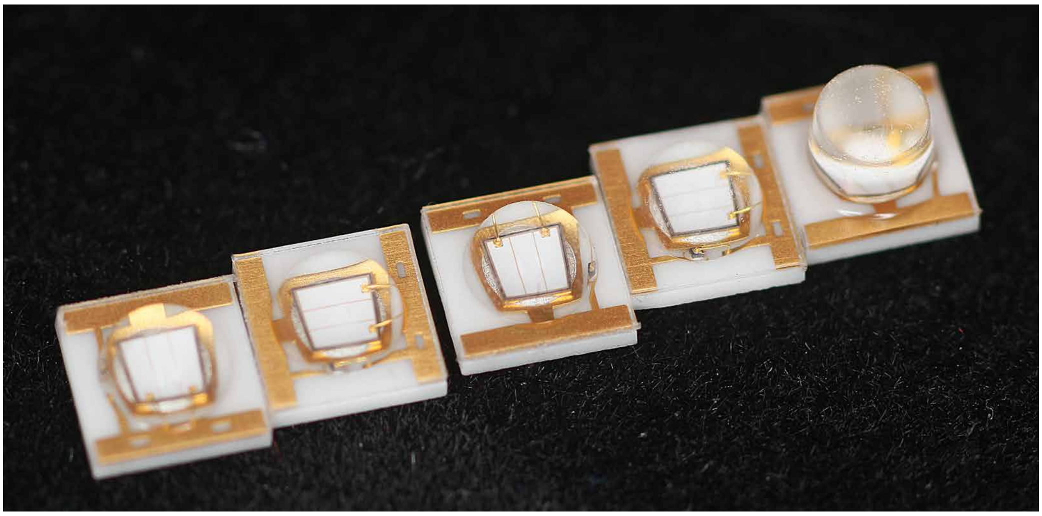
Optotech presents itself as a true "full-spectrum range" manufacturer with LEDs from the short 265nm UV-C wavelength to visible light and up to 1300nm IR. They are currently ramping up production for the newly developed products to reach full mass production in 2016. They are putting all their efforts into improving epilayer structures and surface structuring and efficiency. They hope to reach low-pressure mercury lamp efficiency in approximately three years. Optotech uses flip chip and CSP technology and UV COBs. They offer customization in almost any detail as they have the complete process from the chip to the module in house. So they provide, for example, a combination of blue PC chips and UV-A chip multi-chip packages. As a possible new application for UV LEDs they could imagine some car air purification because the power requirements, dimensions of the LED and the air volume of the car fit perfectly together. For IR, Optotech featured two products, their 1300nm IR LED for security applications and a deep red/IR LED for horticulture.

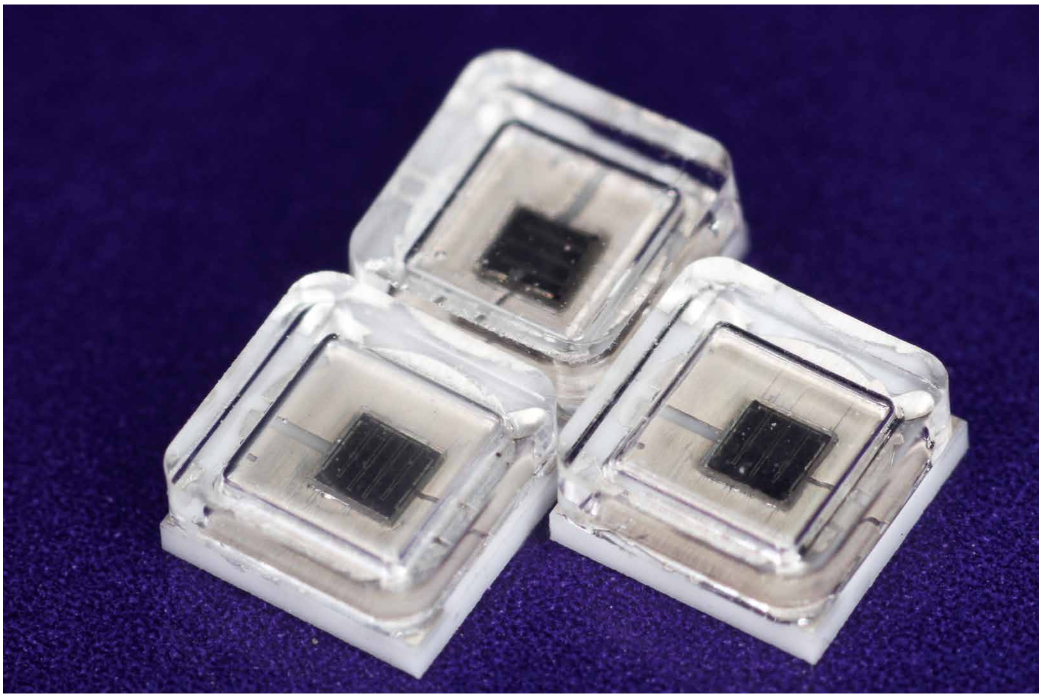
Epistar currently just provides UV-A LEDs down to 365 nm, but is working on UV-C LEDs with reasonable performance. At the current level of UV-C performance, they don't see any relevant market that justifies mass production. Their expectations for UV-A are mostly based on the professional lighting market as costs for these products are higher compared to blue LED based products due to lower yield and up to almost 10 times more expensive packaging materials. IR is the easier market, because they can provide a high power chip that allows for up to 10 times larger illumination distance to most other competing IR LEDs. Furthermore, they provide IR LEDs for bio monitoring. Too find new business opportunities, they are also researching other GaN based technologies like GaN power devices with quite promising results.

Epileds, another skilled LED chip manufacturer, sees a good chance that efficiency of UV-C LEDs, especially UV- HB LEDs, can reach the efficiency of today's state-of-the art UV-C generation methods within three years. The argument for this optimistic assumption is that the technology has many similarities with blue and green LED technologies. This knowledge already exists and should help to solve the problems faster. UV LEDs currently have the best opportunities when narrow bandwidth and directional light is required. The company also aims to extend the product range to long wavelength IR LEDs, but also customized offers. For the latter, Associate Vice-President Timmy Jong sees the necessity of a new applicable business model. On the subject of the green gap, he sees PC converted green LEDs as a viable solution that could be part of the customization business model.

LiteOn, known in other countries for products other than lighting, has been a surprise. Originally coming out of an industry where mass production is the most common business model, the company believes that it isn't the best choice for LED lighting. Niche markets and very specialized, customized products are the offers that they want to provide, and these currently cover 70-80% of their business. Topics like IoT are relevant for them, but in the long term and not in the way that they are usually propagated. For most applications and customers, local concepts are easier, cheaper and faster. Their position on CSP technology is similar. Currently, and in the near future, the market share for this technology won't be high enough for big scale production but it is ramping up due to the demand for display and TV backlighting. With the resulting price erosion, this technology should become affordable and widely adopted. Other relevant technologies look much more promising in the short term, DOB being just one example. The driver technologies for these concepts are provided both in-house and in cooperation with partners. Of course, LiteOn also have UV and IR products. These were demonstrated in their final applications. Due to the extensively discussed efficiency lack of UV-C and even UC-B LEDs, they concentrate on UV-A. IR LEDs are provided for use in medical and other applications.

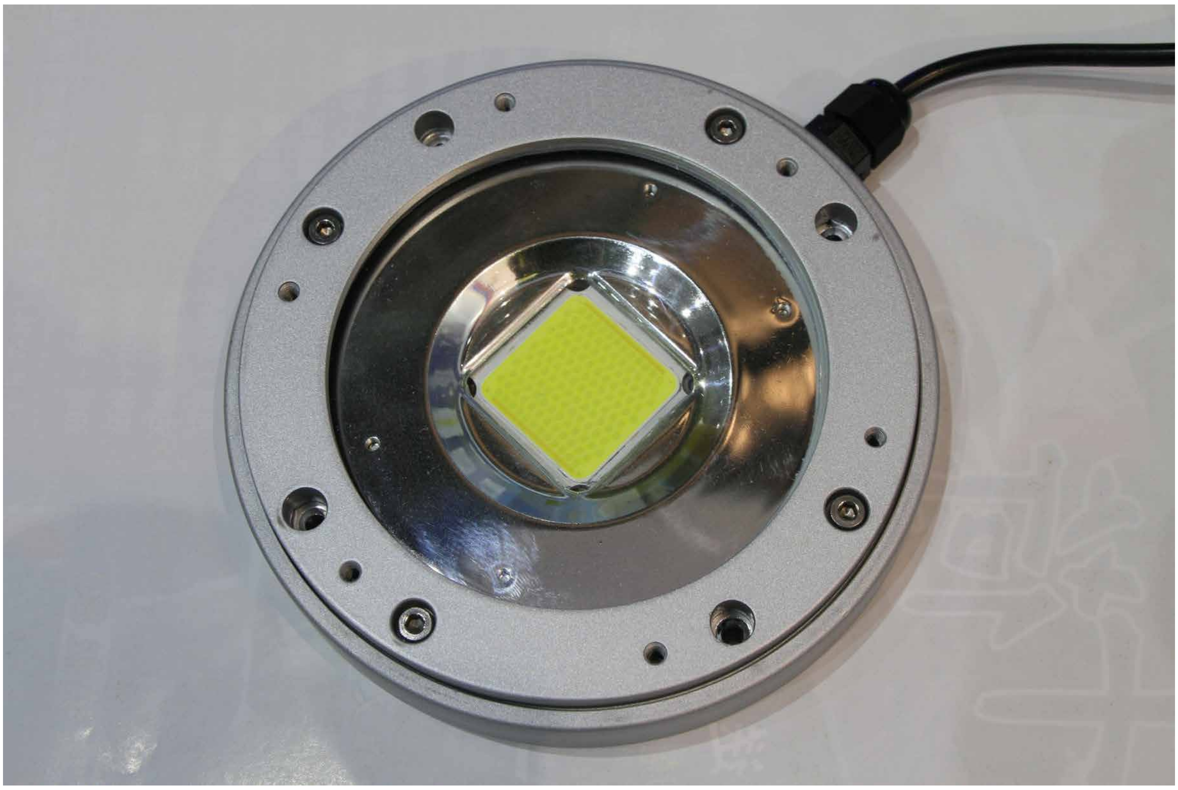
Lextar is a company that has virtually any competency needed for LED lighting in-house. They cover the whole range from the LED to the luminaire and controls. They were one of the few companies at the exhibition with an explicit focus on lighting. Like most companies, they see the commercial lighting market as the most important one. The consumer market might become more relevant in the future. Completely out of scope is the replacement lamp business, as quality is the most important success factor for them. IoT is also a topic, but too many questions are open - for instance, the question of software is not clear. Currently, the development of advanced products for this autumn has priority.





Taiwan's LED manufacturers and packagers offer UV-LEDs in different packages and for various applications

Modules are another way to differentiate and avoid the price war



TSLC is the wafer level packaging specialist within a group of interconnected LED companies. Within this group, chip, packaging and luminaire design skills are available. TSLCs current focus is on IR and UV, as well as special lighting LED packages. Due to price pressure from China, they tend to reduce their activities in general lighting. Instead, the company will focus on the automotive business next year as well as the UV and IR LED business for which they are planning new and improved chips for 2016.

For Everlight, until recently mainly known for their general lighting products and optoelectronics components like optocouplers, the time has come to push more into the UV and IR market segment. In 2015 they have been inspired by technical advances and are getting closer to the performance of industry leaders. The strength of the company is certainly customization of their ceramic substrate based packages for distribution angles between 20° and 120°. Another future topic for them is Vertical-Cavity Surface-Emitting Laser Diodes (VCSEL).

Manufacturers of Other LED and Related Products

Leadray is a luminaire manufacturer specialized in high power applications and street lighting. IP protected copper-FR4 PCBs are their key technology as they recognize heat management to being most important. While the drivers and supplies are standard products, the controls, including software for intelligent street lighting, are both developed in-house and with cooperation partners.

ShinyU, sells both luminaires and modules but their main business focus is on modules. Originally, the company produced vacuum chambers for heat management. With this core knowledge they focus on high power applications from 80+ watts up. They provide “through-hole” heat sinks. Most design and R&D is done in-house, but customized COB designs are realized by their partner companies. In their designs, ShinyU aims for higher brightness, more energy efficient and longer lasting products.

Testing products specialist AMA provides die sorters as well as other testing products for manufacturing for several well-known international brands. The COB show at the sorter with its 20 inch integrating sphere can process 3,000 pieces of 40 mm x 40 mm COBs per hour. Their SMT sorters are capable of sorting up to 25,000 pieces per hour. Depending on customer requirements, they measure different parameters in parallel.

Asensetek, manufacturer of the Lighting Passport, the IOS based hand held light measurement tool, showed their latest app extensions. With these new, and in some cases, very specialized apps the user can measure, display and convert photosynthetic active spectra, or gain spectral information to calibrate professional TV cameras.

There were also companies and distributors there with a more local focus. The exhited products from measurement equipment to raw materials, and drivers to luminaires.

Concurrent Program

As the Taiwan Photonics Festival not only concerns LED lighting, the broad spectrum of sessions and

Manufacturing and testing equipment was also on display

lectures covered topics from photovoltaics to nanotechnologies, from manufacturing to displays, and IoT sensors to LED technology. Celebrating the IYL, the session "International Year of Light – Lighting up the Future", brought together representatives of different photonics organizations from all around the world. The attendees could learn about the different activities. One exemplary, more technology focused lecture from Kevin Huang, Technical Project Manager of R&D at IMEC Taiwan about "Cost Effective Flexible Inorganic LED and Devices" completed this session.
This technology aims to reduce manufacturing costs by eliminating the pick-and-place process as well as wire bonding in some applications, especially for wearables and portable devices. The basic principle of this technology is to bond expandable structures to the wafers and to expand it to the final size. Currently, a 10 times areal expansion is achieved. The inventors expect many new applications from new, curved camera sensors that reduce the effort of designing lenses to RFID, or medical applications to screens and lighting.

Conclusions from the Discussions and Perceptions

The crisis in the EU and price erosion due to Chinese low-cost products seems to have hit the Taiwanese industry hard, leaving them looking for alternative strategies and business options. One of these strategies is to expand business away from the general lighting business into other areas like UV applications. With the technological progress of the last years, UV LED technology has slowly become competitive in more and more applications. Even UV-A is expected to reach an efficiency level to directly compete with UV-tubes within about the next two years. The applications are also often related to industries like medical and some industrial sectors where quality counts more than initial costs. With their high quality standards, Taiwan's manufacturers now approach these business fields, as well as other quality-conscious industries, like automotive.
Another strategy is to add value by offering custom-tailored solutions, especially COB modules including drivers (DOB, DCOB). On top of all these efforts, these companies also recognized service and support to being crucial for their further success, probably even for their survival in this business.
This makes them very competitive with US and European companies and distinguishes them from most Chinese companies. ■

References:
[1] April 2015 - http://www.semiconductor-today.com/news_items/2015/apr/nict_210415.shtml

Lighting with LEDs – More than just Illuminating Objects

Light is more than just vision. It includes aspects of well-being, health and emotions. Dr. Wilfried Pohl, Markus Canazei and Christian Knoflach from Bartenbach report on their experiences and discuss the requirements for LED lighting. They also write about physiological effects and make recommendations for improvements.

How can the needs of people be served by new LED-lightings? LEDs as a digital light source offer new technical possibilities for fulfilling special visual, biological and emotional requirements. At the same time our knowledge about how lighting affects people has increased significantly. This article gives an overview of experiences with LED lighting up until now as well as the latest findings in lighting effects. Recommendations will be given to improve future LED-lighting.

Lighting technology is in a time of ground-breaking changes that can be symbolically described by two milestones. One of them being the progression of the LED from a weakly glowing signal lamp to a highly efficient point light source, and the other being the discovery of the so called "third receptor" in the human eye. It is a photoreceptor containing melanopsin that regulates the discharge of melatonin in the brain and thus has an indirect impact on the circadian (day and night) rhythm of humans. Both milestones can be dated around the year 2001.

The LED as Illuminant of the Future

The LED as a highly efficient and digital light source has triggered a rapid change both in the lighting industry and also in the implementation of illumination. With a common light yield around 120-140lm/W in realistic operation the LED already surpasses all other high-grade luminaires in general lighting. And the end is not in sight! In the coming years the light yield will increase up to around 200 lm/W. At the same time the life span of 50,000 hours outperforms conventional luminants by far (for example a light bulb has approx. 1,000 hours, an incandescent halogen light bulb approx. 3,000 hours, a fluorescent tube approx. 20,000 hours). Therefore although the initial costs (investment) for LED lighting systems are higher, due to the longer life time, the profitability outperforms that of most customary systems.

The characteristic of LEDs to respond to control signals instantaneously, meaning without time delay, is ideal for usage in communication technology (digital light source = electronic unit). The combination of LEDs with light- and movement-sensors, interconnected with complex control and regulation algorithms, turn the lighting into a smart and adaptive system that can react to alterations in its environment (time, weather, etc.) in a flexible way.

A future vision is an autonomously acting "thinking" LED-luminaire, that is integrated into a higher-ranking information and communication network over the "internet of things".

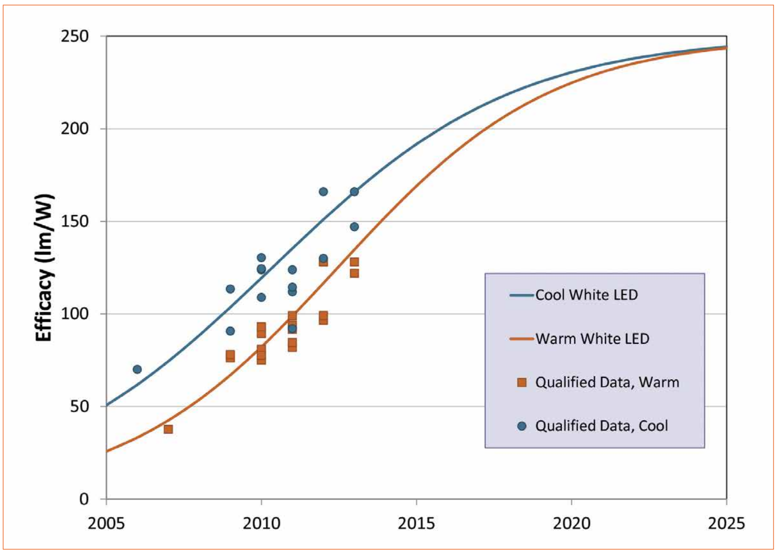


Figure 1: Efficacy forecast of white LEDs, U.S. Department of Energy [1]

Figure 2: LED, optics and luminaire

Merging several color LEDs to a single spectrum, while each LED is dimmable, allows the luminous perceived color to be set in an almost user-defined manner. In so doing, lighting systems can be fashioned with which the perceived color, the intensity and the light distribution can be dynamically modified for each use case or individual requirement.

Newest Findings in Light Impact Research

Third receptor inside the eye

With the discovery of the so called photosensitive retinal ganglion cells in 2001, a new chapter in lighting technology was opened: This so-called "third receptor" (beside rods for scotopic and cones for photopic vision) at adequate intensity, blocks the nightly discharge of the sleeping hormone melatonin by the pineal gland. In experiments it could be shown that this discharge can be abruptly stopped inside a few minutes by illuminating the retina with light of appropriate wavelength and intensity.
While light constrains the flow of the sleeping hormone melatonin during the night it stimulates the production of the hormone serotonin (an endorphin) during the day.
This way light triggers the day- and night-time rhythm of humans and significantly contributes to well-being and health.

This discovery is seen as proof that light is not only needed to see with but also has an impact on physiological processes and directly affects human health. Thus light will, in future, not only be important for the visual environment of people.

Non-visual lighting impacts

Innumerable studies [2, 3] indicate that light does not serve man for seeing (visual perception) only.
Light acutely influences cognitive processes [4] and has a strong influence on various circadian physiological rhythms [5].
In addition, the effect of improving your mood due to bright light in the early morning hours is uncontested [6] and is extensively

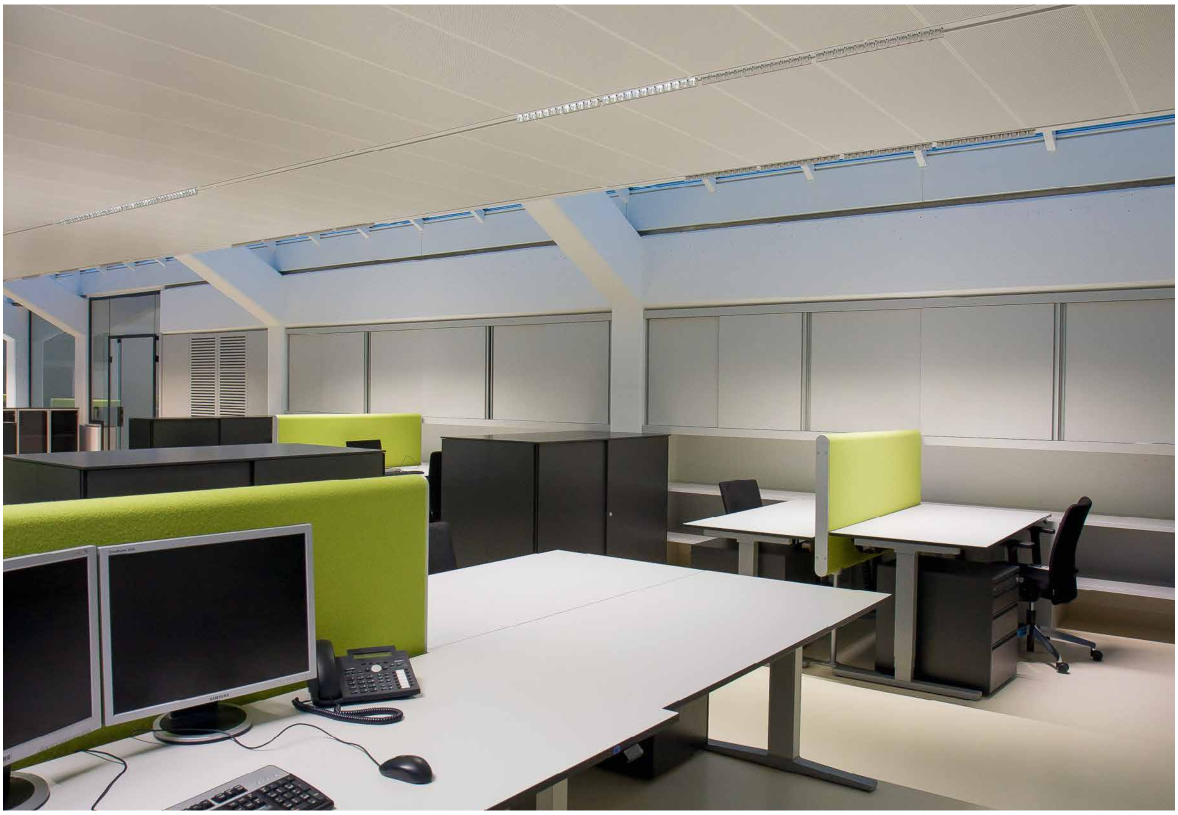


Figure 3: The new R&D office at Bartenbach

employed in the treatment of people with seasonal affective depression.

About 15 years ago the research into non-visual effects of light gained momentum due to the publication of groundbreaking studies regarding the acute nightly suppression of Melatonin [7, 8]. Based on this research, a range of activities regarding non-visual effects of light was determined [9]. As an addition, design recommendations for lighting design taking into account biological aspects were published in 2013 [11].

At the same time, further studies were conducted in order to learn more about the active factors directly related to light (e.g.: brightness, spectrum, point in time and duration of exposure to light). These studies were mainly conducted in laboratories at night with well-selected test person populations. Regrettably research aiming at quantifying non-visual effects of light on humans in their natural living environment during the day has only produced a few explicit results. This fact put a considerable damper on the euphoria regarding this topic.

In addition, the early initiatives for establishing standards for non-visual effects of light were strongly questioned by scientists. Currently the DIN standard committee NA 058-00-27 AA (Effects of light on man) is discussing the question, if the action spectrum for non visual effects of light previously based on the acute nightly melatonin suppression (with a maximum spectral sensitivity at 450-460nm – Figure 4), should be replaced by the spectral sensitivity of the melanopic ganglion cells in the human eye (with a maximum spectral sensitivity at 480-490nm – Figure 4). This would represent a significant paradigm shift in the evaluation of the spectral distribution of light.

Furthermore the scientific evidence for the published design recommendations regarding non-visual effects of light is quite weak [12].

For generating specific non-visual effects of light on man a deep understanding and knowledge is necessary, that is currently not in existence, and that could only be gained by future research with representative random samples in naturalistic settings und long periods of observation. Currently it is not known if it will be possible in future to influence man´s cognitive, endocrine and autonomous physiological processes with the aid of lighting based on scientific findings and thus to assign a new and sustainable added value to the factor “light”.

First Experiences with LED Applications

The lighting industry is competing in terms of efficiency and new records are set frequently. The inconsiderate usage of the technological possibilities involves the danger of creating useless or very bad solutions that in the end raises questions about the complete technology.

For example, the combined spectra of several LEDs entail the risk of being perceived as bad color quality, or specific surfaces may seem unnatural. The combining of different color LEDs can lead to irritating color shadows, or the commonly used pulse width modulation (PWM) for dimming the LEDs can generate disturbing flicker effects with moving parts. The extremely high light density of high power LEDs (>50 Mio cd/m^2) can produce uncomfortable light pressure and strong glare in the radiation field.

The quality criteria stated in relevant harmonized standards that are used in lighting engineering, are not suited for this kind of LED illumination.

The LED as a digital light source (and electronic component) has made the standards and interface definitions that have established over the decades invalid: Where it was self-evident to replace a lamp, no matter from which manufacturer or nationality (even if the installation was 20 years old), the built in components and LEDs nowadays are often no longer available or cannot be dismantled. At best, the lighting component can be replaced together with the electronics (as one element) and often is deliverable solely by the original vendor. The LED is, at present, a product that is outperformed by a better LED within months. But at the same time it has a life span of several decades. All this generates large uncertainty with handlers and consumers and makes long term planning difficult.

To use the potential of LED-technology in a positive way for the end-consumer, new rules (technical but also qualitative standards) are needed. The requirement, therefore, is, amongst other things, the establishment of new quality criteria to quantify these benefits.

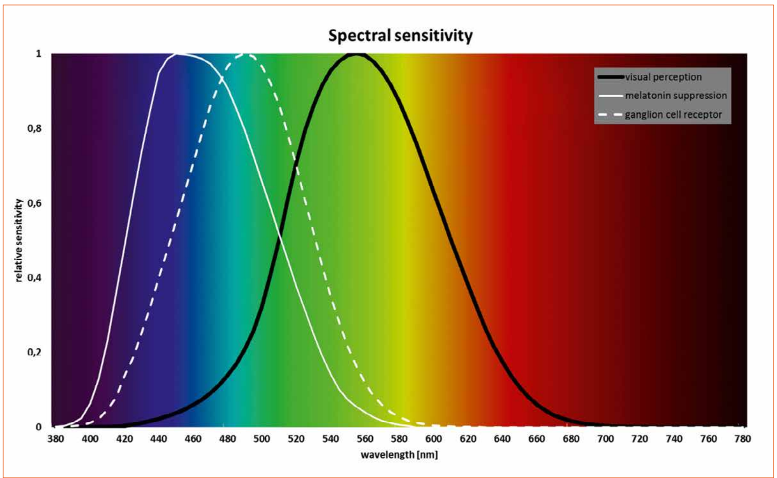


Figure 4: Spectral sensitivities of the human eye

Color Rendition

Color rendition (color rendering index, CRI) is an important spectral quality criterion of a light source. This index tells us to what degree colors are rendered correctly in comparison to a reference light source (daylight or thermal radiator) when illuminated by an artificial light source.

Figure 5: Color rendition (source: http://www.ledigma.lt/technology/)

The early LED generations often had CRI values of less than 80 and thus did not meet the requirements stipulated in the standards for interior lighting. At the same time, it has been noted that the color saturation of objects illuminated by LEDs, at least in part, appeared to be considerably stronger and also more appealing. This fact and the knowledge regarding the outdated elements in the calculation of the CRI determination method [13] motivated many research institutions across the world, to research color rendition once again.

Currently some studies [14, 15] indicate that there are two diametrical aspects are contained in the theoretical construct of color rendition, namely color fidelity and color preference. Regarding the latter, the distortion of color impressions leaning towards an increased color saturation play a particular role (due to the fact that more saturated colors are often preferred) and thus complements the concept of color fidelity.

This finding is, amongst others, the reason why the International Commission on Illumination (CIE) formed the new Technical Committees TC 1-90 ("Color Fidelity Index") and TC 1-91 ("New Methods for evaluating the color quality of white light sources"). They have been tasked to develop updated color fidelity metric.

Currently various updated color fidelity metrics [16, 17] are discussed to become the replacement for the hitherto existing calculation regulation. They show that particularly light sources with a color temperature below 4000 Kelvin and tri-phosphor fluorescent lamps with a previous CRI value between 80 and 85 should often have a lower color fidelity value and thus would actually not meet the lighting standards. By contrast, light sources with a CRI value of greater than 90 according to the hitherto existing calculation rules continue to have updated CRI values of the same magnitude.

Currently the color rendition of saturated test colors is often cited as a quality criterion for the spectral quality of light. Updated calculation regulations show, for instance, much higher color rendition values for a test color with a saturated shade of red (R9 test color) as determined with the previous calculation method. Consequently the color rendition of the test color R9 does not represent a valid quality criterion for the spectral quality of a light source. For other saturated colors the results are not pointing clearly into one direction.

Promising candidates for a color preference metric, such as the gamut area index [18] or the CQSg [19], are currently suffering from the problem that there are no concrete recommendations for the characteristic of the calculated values, and, that it is not yet clear in terms of specific

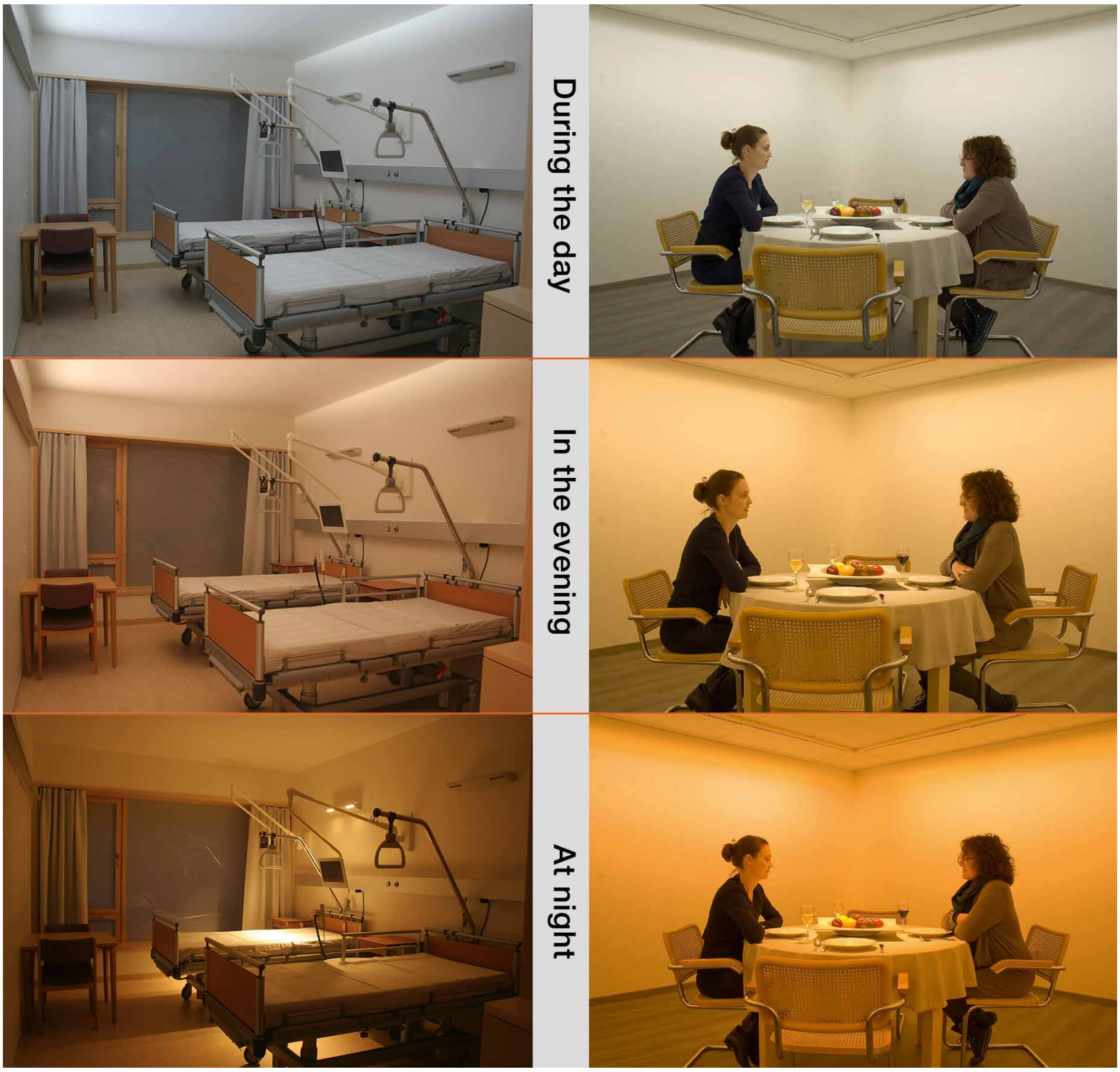


Figure 6:
Dynamic illumination of a hospital ward and a domestic dining room

applications which balance would represent an optimum between the values of color fidelity and color preference.

Currently there is a deep disagreement regarding the question of if the hitherto existing color rendition computation method should be updated at all. This is shown by the contradicting position papers authored by the European and American Illuminating Engineering Societies. Thus Lighting Europe [20] is in favor of retaining the hitherto CRI calculation regulation. Contrary to this the Illumination Engineering Society IES [21] advocates an update of the color fidelity computation and for the introduction of an additional calculation of the color saturation potential of a light source.

Despite these disagreements, it has a lot to commend an updated calculation regulation for the determination of color fidelity of a light source.

In conclusion, it shall be mentioned that due to the rapid development of the LED technology during recent years the color rendition of LEDs has greatly improved – quantified by both, as per the traditional method as well as per the updated computation models.

Dynamic artificial lighting

Generally dynamic lighting varies the lighting level, the distribution, and the color temperature of an interior space. The transition of the lighting parameters occurs slow enough to be below the awareness threshold (subliminal) mostly lasting more than 15 minutes.

The primary objective of dynamic lighting is either controlling artificial lighting in the interior subject to the time of day in order to facilitate certain specific non visual effects of light on mood, sleep, cognition and physical activity or supplementing missing natural light with artificial light with the aid of sensors in order to increase visual comfort and to establish an energy efficient means of adding artificial lighting.

Currently the scientific evidence regarding the non-visual effects of dynamic light is quite limited. Today there are only a few well managed studies (De Kort, 2010 [21]; Barkmann, 2012 [22]; Boyce, 2000 [23]; Hoffmann, 2008 [24]; Barrick 2010 [25]; Canazei, 2013 [26]; SSL-erate Deliverable 3.2., 2015 [27]) indicating that dynamic lighting in offices, class rooms, in homes for elderly people and for shift workers some positive effects can be achieved. It can be assumed that in these studies the interior lighting plays an important role and had its positive non-visual effects particularly during the early morning hours (up to two hours of getting up), in the late evening (up to two hours prior to going to bed) and during the night.

On the other hand, it is uncontested that the dynamic addition of artificial lighting as a supplement for natural light can reduce the energy consumption of artificial lighting considerably.

Figure 7, for instance, shows that – based on the simulation software DALEC – the energy consumption of the lighting of an office in Innsbruck (Austria) with a south-facing facade and in compliance with the standards can potentially be reduced by 27 – 54%.

From a technical point of view, dynamic interior lighting can either be realized by mixing different color LEDs with / without a white LED (RGB- respectively RGBW mixing) or by mixing white LEDs of different color temperatures. Although the chromaticity coordinates of the resulting spectral distributions can

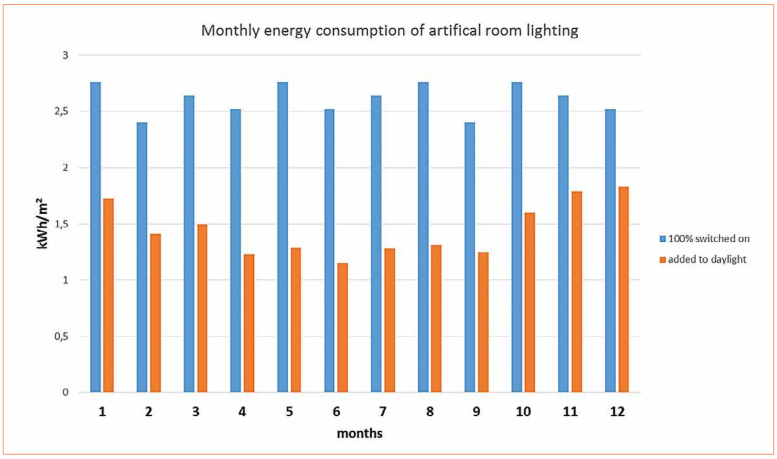


Figure 7: Computation of the monthly energy saving potential of dynamic LED lighting (Source: dalec.net)

be kept close to the black body radiation (Planck´s law), this method of mixing light does not represent a quality criterion for dynamic lighting per se. It is recommended to also spectrally evaluate the mixed spectrum by means of updated color rendering computation methods (e.g. CRI 2012 [28]).

Flicker

Flicker is the temporal modulation of the luminous flux of a light source and can be visible or invisible. As is currently known, human ERG (electroretinogram) signals at light frequencies up to 162Hz [30].

Flicker can induce epileptic seizures, headaches, fatigue, eyestrain, blurred vision, migraines, and distraction, reduce visual performance and altered perception of moving objects [29].

Flickering light matters in applications with fast moving objects, where eyes have to move quickly (e.g. while reading or searching) and where video cameras are used.

From a technical perspective flicker can be described in terms of its modulation frequency, modulation amplitude, DC-component, duty cycle and modulation waveform. Figure 8 shows examples of flickering light sources.

The quantity of flicker for LEDs strongly depends on the used electric components and on the

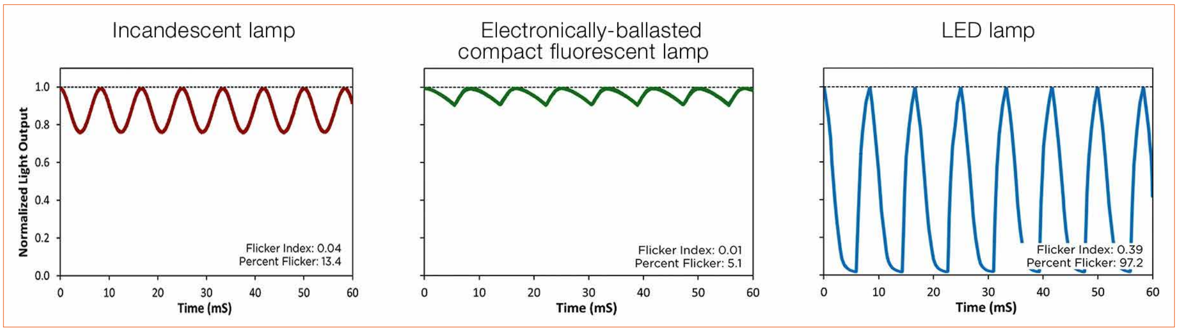


Figure 8: Temporal modulation of light sources [31]; cited flicker indices see IES [34]

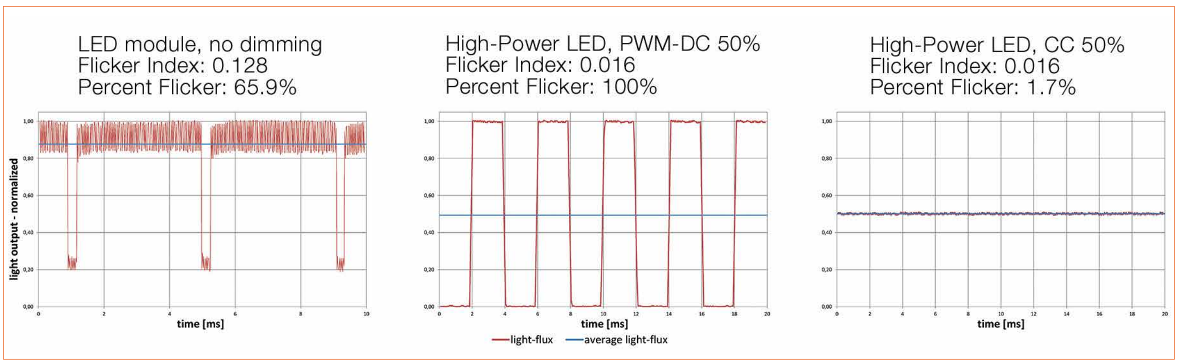


Figure 9: Temporal modulation of LEDs, examples [35]

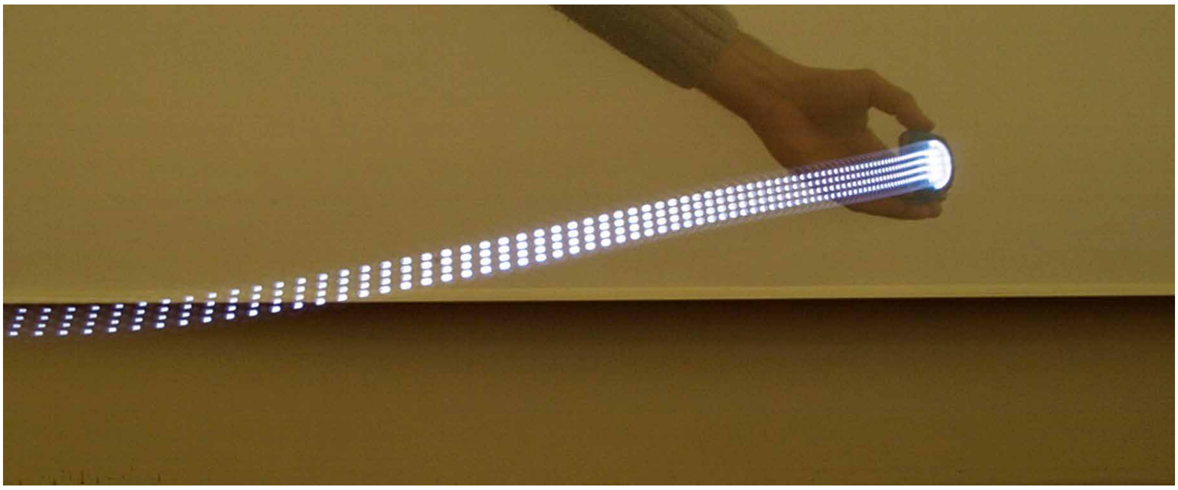


Figure 10:
Phantom array effect

operating conditions (e.g. dimming, see Figure 9). At the moment these details are not specified neither for LEDs and ballasts nor for LED luminaires and thus it is difficult to decide on the quality of products concerning flicker.

Application-related factors which modulate the impact of flicker are the duration of exposure, stimulated retinal area, location in the visual field, brightness of the flickering light source, and local luminance contest of the light source to its surrounding.

Currently recommendations to mitigate health and safety-related effects of flickering light are mainly based on studies dealing with stroboscopic and phantom array effects [32]. Research on physiological effects of flickering LED lights after hours of exposure are still needed to quantify the long-term impact of invisible flicker.

IEEE recently recommends [33] modulation amplitude *(max. - min. light output / max. + min. light output)* smaller than 8% of the flicker frequency for the normal population and modulation amplitude smaller than 3.33% of the flicker frequency for the flicker-sensitive sub-population. Additionally, flicker should be below 10% modulation for flicker frequencies below 100 Hz.

Glare

Vision is strongly influenced by the luminance distribution in the field of view. Especially in sceneries with objects much brighter than the adaptation level of the eye these potential sources of glare can decrease visual comfort as well as visual performance. In a working environment this reduces productivity and in other applications like traffic it might even be a threat to human life. Fortunately there are well-established metrics for glare that are commonly used all over the world. Sticking to threshold values defined in standards should prevent unpleasant or dangerous consequences of artificial lighting systems. Widespread examples are the CIE Unified Glare Rating UGR [36] for discomfort glare and the Threshold Increment TI [37] for disability glare.

Standards specify e.g. UGR ≤ 19 for office lighting [38] or TI ≤ 15% for certain situations in road lighting [39]. Is this really the whole story and thus glare a topic completely under control?

The Unified Glare Rating UGR is intended to describe discomfort glare in interior space caused by artificial lighting devices. According to the "International Lighting Vocabulary" discomfort glare is defined as "glare which causes discomfort without necessarily impairing the vision of objects" [40]. Despite criticism that UGR is too complicated and difficult to apply in practice there have been many studies and publications [41, 42, 43] indicating the adequacy and applicability of this method.

When applying UGR calculation in daily practice an attentive designer faces several problems:

- Different light planning programs compute different UGR-tables for the same luminaire. [44]
- Even within one software program the UGR-table depends on default settings that vary from country to country (Spacing-to-Height-Ratio might be 0.25 or 1.00).
- Typically there is no check if the dimensions of the luminous area are within the range specified by the CIE: Its solid angle has to be larger than 0.0003 steradian, which is a cone with an aperture 2 x 0.56°, (compare with average sun angle 2 x 0.27°). And it has to be smaller than 0.1 steradian corresponding to a cone with an aperture 2 x 10°. As a consequence the UGR-values for LED points calculated by standard software are ways too high.

Generally the undiscerning use of UGR-tables is questionable. These values are based on a regular and closely spaced luminaire arrangement. For a ceiling 1.6 m above the user's eye the luminaires are placed at a distance of 0.4 m (Spacing-to-Height-Ratio 0.25) and thus the whole ceiling is paved with luminaires. When using real world arrangements and calculating UGR-values for certain positions in the room the values can be much higher than the values in the UGR-tables. But there can even be no glare at all because there is no luminaire in the field of vision. In

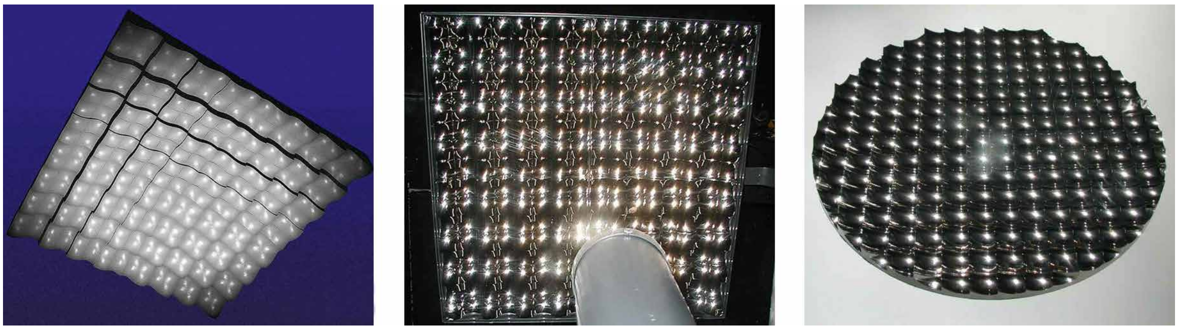


Figure 11:
Light spot decomposition, free form facets for outdoor and indoor applications

reality the UGR-value depends not only on the luminaire data, but also on the observer's position, his viewing direction and the positions of the luminaires. Such exact calculations for a real project can be performed in software based on UGR formula and it is astonishing to note that the UGR-values specified e.g. in EN 12464 [38] explicitly reference the use of the tabular method stating that the threshold values when using the UGR formula are to be discussed.

For both methods to calculate UGR-values, the tabular method and the usage of the UGR formula to make more detailed predictions, the restrictions concerning the solid angle of the luminous areas of the luminaires are a crucial problem. These difficulties are currently ignored by the light planning software available on the market. Especially when using LED luminaires the luminous areas of the single optics frequently are far below the minimal solid angle of 0.0003 steradian. In many, but not in all cases, it is arguable to average over larger areas with dark regions in between. Sometimes even the dimensions of the housing are used as luminous area that can dramatically reduce the UGR values of the luminaire. The luminaire data provided by light fixture manufacturers e.g. in EULUMDAT- or IES-format contain only very simple models of the luminous area (rectangle or disk) and thus each software relying on these data is forced to average the luminance over the whole specified area. The detailed guidelines on how to handle luminous area and luminance for certain types of luminaires in CIE 117, Appendix C "Luminaire data" [36] are widely ignored by manufacturers as well as software engineers of light planning programs.

The CIE Technical Report CIE 147-2002 "Glare from Small, Large and Complex Sources" [45] proposes adaptations of the UGR calculation to overcome some of the problems but these suggestions have not been realized yet. As there seem to be some inconsistencies in these adaptations other algorithms have to be proposed in future [55]. At the moment there is a lot of research on discomfort glare that is driven by the problems of the UGR concerning LED luminaires [46, 47, 48].

A method to reduce glare to a minimum called "light spot decomposition" was proposed many years ago [49, 50, 51]. This method has been patented in many countries all over the world [52] and has been realized in projects and products. The idea is to split up the light source into many small light points that can be separately observed from any point of place within the illuminated area.

When comparing such a light spot decomposition with a conventional light source with the same luminance concentrated on a compact luminous area the advantages of the decomposition is quite obvious. It is much more interesting to match against a conventional lighting device with the same luminous area with a more or less constant luminance. Here the luminance of the light spots is far higher than the luminance of the conventional device. Perception Studies in the framework of the Competence Center Light [53] suggest that in this case the light spot decomposition might induce similar or even worse discomfort glare but it seems to be superior concerning disability glare.

In the "International Lighting Vocabulary" disability glare is defined as "glare that impairs the vision of objects without necessarily causing discomfort" [54]. As the visibility of objects on the street largely determines security in road lighting it is of vital interest to concentrate on disability glare in these standards [39]. The established metric for this glare is the Threshold Increment TI [%] based on the veiling luminance in the human eye created by sources of glare [37]. The TI-value is calculated from the vertical illuminance at the observer's eye (illuminance perpendicular to the line of sight). As the luminaires are at large distance the luminous intensity of the luminaires in the direction of the observer's eye are the crucial factors for a given luminaire arrangement. Thus the threshold increment does not reflect positive effects of light spot decomposition on disability glare. Additionally, all these calculations are based on photopic vision that seems to be odd for road lighting at nighttime. During the last years mesopic vision, in general, and the visibility and the visual performance in mesopic conditions, in special, are in the focus of Technical Committees (TC) of the CIE [56, 57] and of researchers all over the world [58, 59, 60, 61].

Another problem is that state-of-the-art LED street luminaires has acceptance problems in the population due to the high luminance of today's high-power LEDs. This high luminance might not pose a security risk or even influence disability glare but it can be seen in the context of discomfort glare in outdoor lighting. These topics attract more and more interest and some CIE technical committees are engaged in finding new answers [62], [63], [64] that also might be incorporated in future standards in road lighting. Like different developer of high-end LED street luminaires, Bartenbach, with a 10 year history of studies in visual perception, currently focuses on new ideas for tunnel-lighting [65] as well as research on street lights with minimized glare [66].

Stable perception

Even if the luminance is within a range where no glare is to be expected the visual performance and especially the contrast sensitivity $LB / \Delta L$ (LB is the environment or background luminance and $\Delta L = L - LB$ is the difference of the task luminance L and the background luminance LB) according to [67] depends on the task luminance L as well as on the luminance of the environment LB (Figure 12). This so-called "model of stable perception" has been adopted and additional studies have been performed during the last decades. It means that you need balanced luminance distributions in the field of view to reach a stable perception. Ideally the infield L is brighter than the environment LB. Nowadays such considerations are even taken into account by standard planning software due to a differentiation in requirements in standards as EN 12464-1 [38]: The area of the visual task, the direct environment and the background are examined separately with different demands.

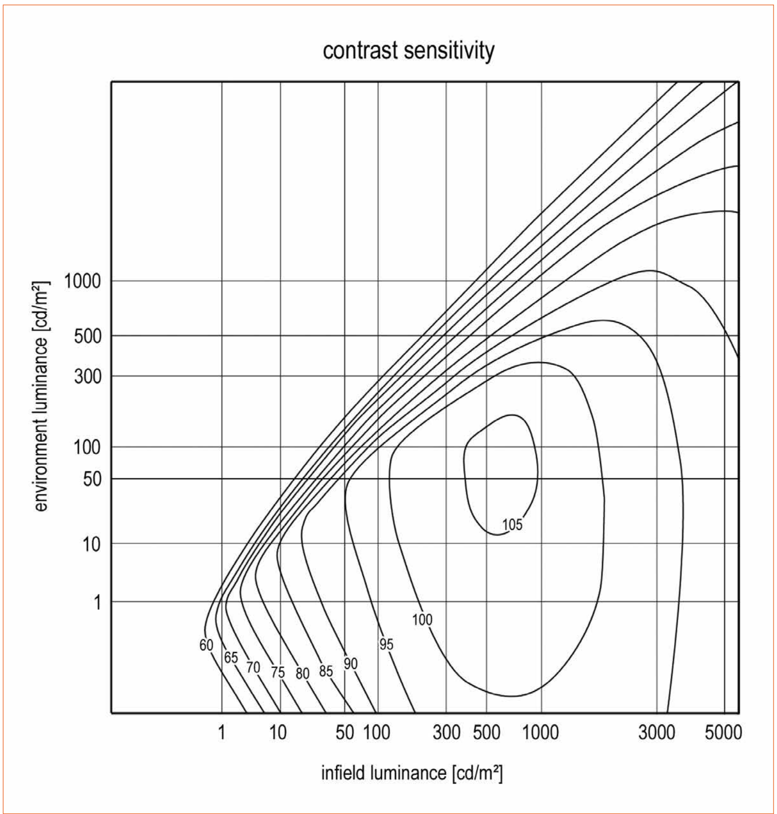


Figure 12: **Contrast sensitivity dependent on luminance of infield and environment, data based on Schumacher R. O. [67]**

Energetic and Ecologic Aspects

Worldwide, about 20% of electrical power is used for lighting. In industrial countries that is approx. 1,000 kWh of final energy per person per year. The bulk of this energy is gained from fossil fuels, whereby about two thirds of this obtained energy is lost on its way to the end-consumer due to thermal losses (primary energy factor). The approximate 200-300 liters of oil that are therefore consumed per person and year are a substantial part of the economic footprint.

In some buildings, for example in administration buildings, the percentage of electrical energy for lighting amounts to 50%. In that case the illumination becomes an important factor on the way to zero- or low-energy houses. LED technology offers the possibility to meet these energetic requirements in future.

Design Aspects

Lighting design is more than the planning of stipulated light intensities and luminance levels given by normative guidelines. Lighting design means the creation of an appearance (e.g. of a room), which complies not only with the technical requirements but also with the visual and non-visual (biological) as well as the emotional and aesthetic requirements of the users. Adequate illuminance levels horizontal and vertical (regarding room utilization, visual tasks, etc.), proper balanced luminances in the field of view, control of direct and reflected glare, and adequate color rendering are only minimal conditions for good lighting.

Visual perception is, first of all, a mental procedure and not only a pure sensation (like e.g. a thermal sensation, which causes feelings of cold or heat). To see means to receive information about our surroundings, about distances, surfaces, textures, what happens around us, etc. And all this information arouses emotions. Our perception is very selective, prejudiced by our personal experience, and is influenced also by our actual mental state, history and expectations.

The perception of the visual environment cannot be measured quantitatively, and therefore cannot be mathematically planned or converted. Visualizations by computer simulations (renderings) or scaled models are just aids, ultimately the true effects can only be experienced in the real situation.

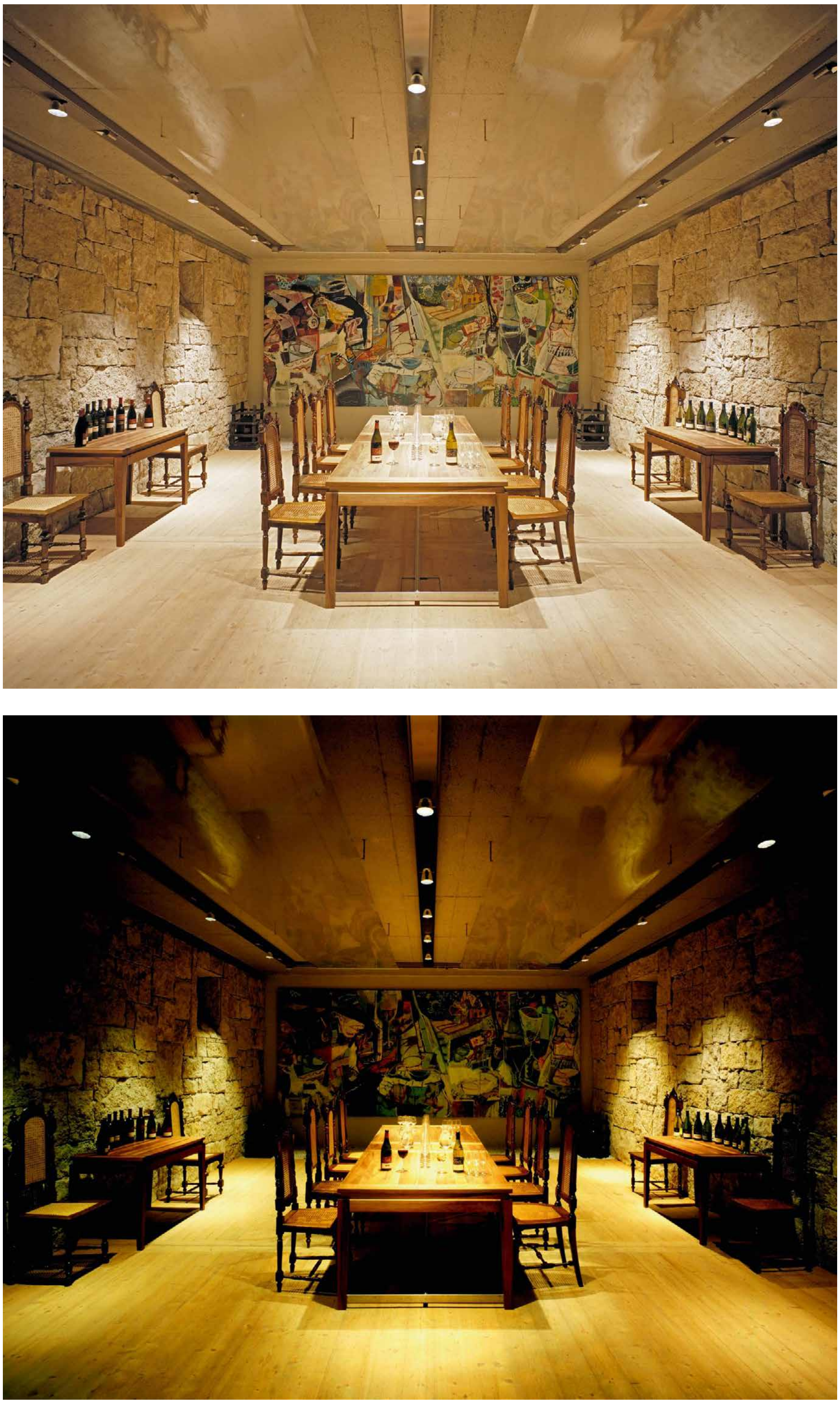


Figure 13: **Vineyard, comparison of two different lighting atmospheres (© Peter Bartenbach)**

The pictures of figure 13 show the creation of two milieus only by changing the light color and light distribution.

From an architectural point of view, lighting is a means to express and underline the desired character of the building or room, which may be defined by an overall design style of the architect, by the use of a special room etc. From a functional point of view we have to take care that basic visual requirements have to be fulfilled to serve for an appropriate visual perception, dependent on the application. For example, in administrative buildings (offices, etc.) functionality is the key element (to satisfy ergonomic, safety and communication requirements), whereas in residence and tourism aspects like comfort, aesthetics, value, and social status are in the foreground.

Conclusion

LED-technology in cooperation with communication technology offers new possibilities for high grade and individual lighting solutions. To create a sustainable benefit for the users, generally acknowledged criteria must be set up, with which the new qualities of light can be assessed and measured. Furthermore, the non-visual effects of light on the human being must be better understood to be able to create "healthy" light.

The lighting community is facing the unique challenge of changing the value of lighting in society from an understated and cheap topic to an important and well-noticed issue regarding life quality, health and life style.

And, without any doubt the LED-technology provides the potential to cover the increasing need for light while at the same time reducing energy consumption. ■

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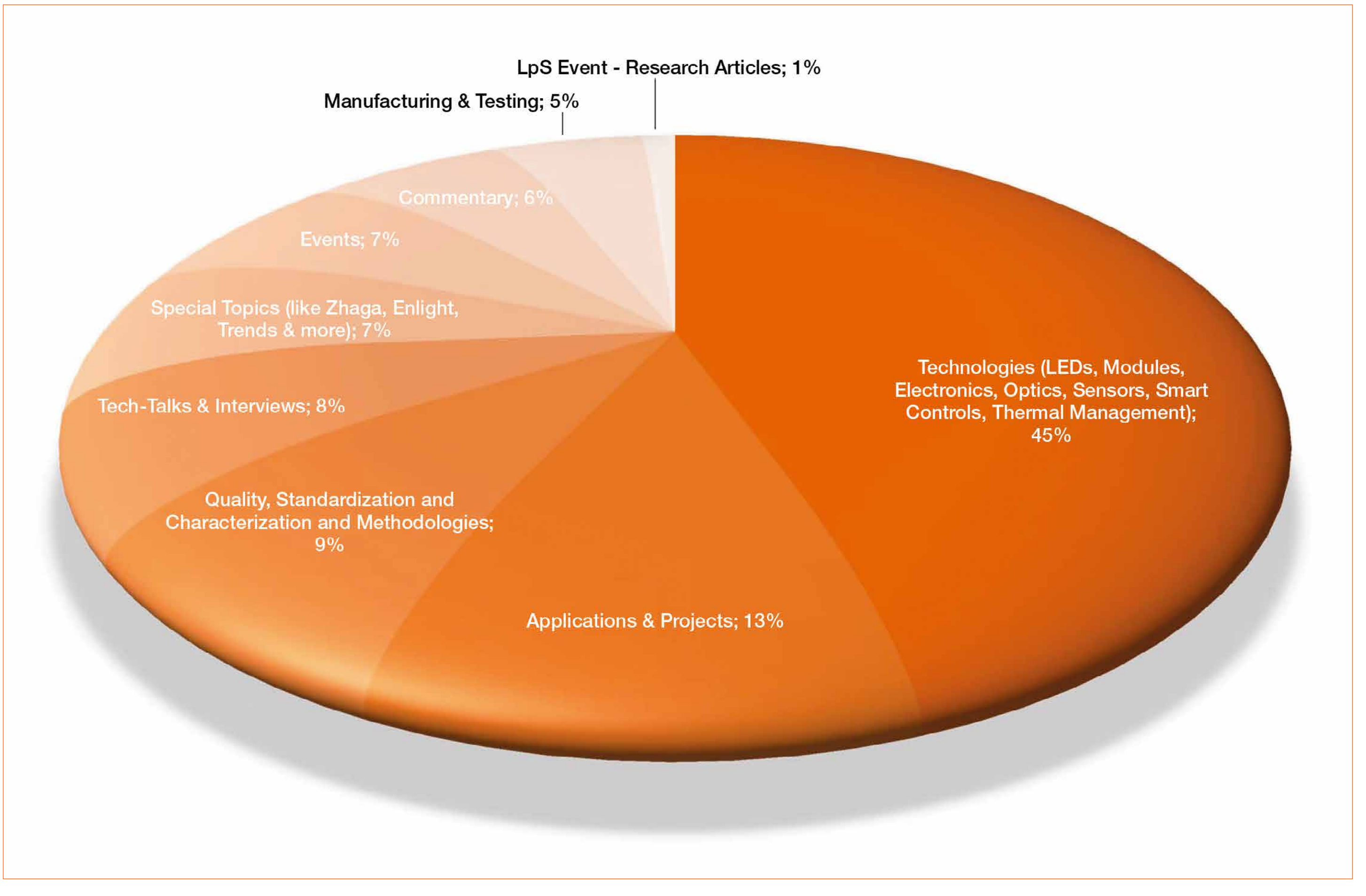
50 Issues Full of Technical Articles to Support the LED Lighting Community

In celebration of the publication of the 50th LED professional Review, a complete content list has been prepared for your convenience. In addition, an "Editor's Choice" article with a short abstract has been selected for each issue based on the estimation at the time of the original publication.

The 50 issues with over 3,200 pages of information cover all relevant topics from light generation to quality issues, from measurement to manufacturing, from optics to electronics or standardization and regulations. The pie chart below shows the percentage of articles per topic.

Some interesting statistical data:
The average number of pages doubled from 40 pages in the first year to 80 pages in 2014. The current average number of pages in 2015 so far, is 99. The first issue was the smallest with just 14 pages. LpR50 is currently the longest issue with 120 pages, followed by LpR 48 and LpR 33 with 108 pages.

Taking this issue into account, more than 400 articles have been published, Most of the technology articles are related to electronics, followed by thermal management and light generation.



LpR 50 | July/Aug 2015

Editor's Choice: Exclusive Interview: Nobel Prize and Global Energy Prize Winner Prof. Shuji Nakamura

Professor Nakamura gave an exclusive interview about the developments and future of solid-state lighting. Siegfried Luger talked with Professor Nakamura about LED substrate technologies, violet and ultra-violet emitters, nano-technologies, OLEDs and laser technologies.

CELEBRATION ISSUE

LpR 49 | May/June 2015

Editor's Choice: 3-Pad LED Flip Chip COB

LED flip chip on board has already demonstrated its advantage in lower thermal resistance and lower packaging cost over the traditional wire-bonded LED COB. A 3-Pad LED flip chip COB was invented to further reduce the thermal resistance. The advantages are discussed and hints for designing and manufacturing are given.

LpR 48 | Mar/Apr 2015

Editor's Choice: EnLight Project Outcomes

A bundled series of comprehensive articles discloses details and technical guidelines for system architecture, advanced sensor and controls, the modular luminaire architecture, new possible form factors and light effects as well as application scenarios with demos and user validation.

ENLIGHT
Energy efficient & intelligent lighting systems

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LpR 47 | Jan/Feb 2015

Editor's Choice: Practical Estimation of Measurement Times in Goniospectro-radiometry and Goniophotometry

Two different typical SSL-sources are investigated and a practical guide is provided for choosing a measurement setup with respect to detector, resolution, size of the sample and compliance to corresponding standards regulations.

Leading Article
2015 Year of (LED) Light
by A. Prasad, LED professional p 32

Tech-Talks Bregenz:
Mehmet Arik, Associate at Ozyegin Univ.
Compiled by A. Prasad, LED professional p 38

Research
LED Office Lighting for Improved Well-Being and Performance
by Katrin Möller et al., Competence Center Light p 42

Technologies
A New Approach to the Design of Driverless AC LED Light Engines
by Peter W. Shackle, Photalume p 48

Practical Estimation of Measurement Times in Goniospectroradiometry and Goniophotometry
by Günther Leschhorn, Instrument Systems p 54

Smart Controls
Street Lighting Evolution through LED Technology
by Sandra Solán, ELT Electronic Division p 62

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Guidance on Specifying Solid State Lighting Luminaires
by Jaap Nuesink & Michael Schoof, DEKRA Certification p 66

Trends
Making Light Work – Light Sources for Modern Lighting Requirements
by James Gourlay, Design LED Products p 72

LEDs are Revolutionizing Light – The Past and Future of Lighting
by Stephan Wegstein, VESTEL p 76

LpR 46 | Nov/Dec 2014

Editor's Choice: Tech-Talks Bregenz with Jiangen Pan, Founder & CTO of Everfine

The interview provides valuable insights on the ever-increasing demands on measurement equipment, new solutions for LED measurements, and, furthermore, Prof. Pan's views and contributions towards global standards and how he works in his "thinking laboratory"

Tech-Talks Bregenz
Jiangen Pan, Founder & CTO / Everfine
Compiled by A. Prasad, LED professional p 28

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LpS 2014 – Fostering the Spirit of Innovation and Engineering Arts
by A. Prasad, K. Fink & A. Grabher-Meyer, LED professional p 34

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New Binning Strategy for White LEDs to Improve the Color Quality of Interior Lighting
by P. Bodrogi & T. Q. Khanh, Technical Univ. Darmstadt p 48

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Cost Issues in the SSL Production Chain - From Substrate to the Luminaire
by J Norman Bardsley, Bardsley Consulting p 52

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Cost Saving Potential with Automation and Well Designed Processes
by Olaf Baumeister, BJB p 56

Managing Manufacturing and Supply Chain Challenges in LED Luminaire Design
by Gelston Howell, Sanmina p 62

Optics
Advanced Optical Plastics Materials for LED Lighting Applications
by C. Van Nuffel, E. Wu, P. Jackson & M. Sans Peña, Styron p 66

Development of a Workflow for Colored Ray Data
by Nicole Stubenrauch, TechnoTeam Bildverarbeitung p74

Testing
Thermal Transient Testing of LEDs for More Reliable SSL Products
by Andras Poppe, Mentor Graphics p 78

LpR 45 | Sept/Oct 2014

Editor's Choice: High Color-Rendering, Full-Visible-Spectrum LEDs

The first wave of conventional white LEDs primarily focused on lumens per Watt. Currently LEDs are catching up in regards to light quality using different approaches like violet-pumped, full-visible-spectrum LEDs. The interrelated challenges and advantages are discussed.

LpR 44 | July/Aug 2014

Editor's Choice: Discomfort Glare Perception of Non-Uniform Light Sources in an Office Setting

Luminaires with increasingly non-uniform luminance patterns are becoming mainstream, making discomfort due to glare an important topic. Based on the research results of an office setting, the currently used formulae to predict discomfort glare are reviewed.

LpR 43 | May/June 2014

Editor's Choice: Tech-Talks Bregenz with Martina Paul, General Secretary at CIE

The rise of SSL with its ever increasing speed of transitions challenges the lighting industry as well as standardization organizations like the International Commission on Illumination (CIE). It is discussed how to define standards that will last as long as possible while being as clear and precise as possible.

LpR 42 | Mar/Apr 2014

Editor's Choice: Solder Joint Reliability of LED Packages

There are some critical steps in the manufacturing process of LED lighting products that affect lifetime and reliability; one of these is soldering LEDs on MCPCBs. Based on studies about solder joint reliability in respect to thermal stress, package size and design, the failure mechanisms are discussed.

LpR 41 | Jan/Feb 2014

Editor's Choice: Photometry Standardization Developments for OLEDs and LEDs

Never before was the influence of external parameters as significant for a measurement result as it is now. For this reason, the review of existing standards and necessary revisions must be done stringently. The article reports about the ongoing work and the expected revision of TC2-71.

LpR 40 | Nov/Dec 2013

Editor's Choice: Interview with Mikolaj Przybyl & Michael Gall from GL Optic

The progress in LED technology encourages many people with good ideas to develop LED lighting products, but some are not lighting specialists or metrologists. They all need to test, measure and verify their developments. The interview sheds light on the challenges of LED measurement and LED measurement standards.

LpR 39 | Sept/Oct 2013

Editor's Choice: Reliability Oriented Design of LED-Based Light Sources

The transition from traditional light sources to SSL systems requires a different design philosophy to achieve the advantages offered by LEDs. The key approach based on the parallel design of thermal, electrical, optical and spectral properties of the light source is explained, differentiating between versatility and efficiency.

LpR 38 | July/Aug 2013

Editor's Choice: OLED Technology in Lighting Applications - Current Status and Outlook

Prototypes and niche applications with OLEDs for lighting have been demonstrated over the past few years. Now there are indications that OLED technology is ready for mass production or at least will be ready very soon. - An analysis of the current status and future perspectives of OLED technology.

LpR 37 | May/June 2013

Editor's Choice: Protecting LEDs from Electrical Overstress Faults

While LEDs are reliable under standard conditions, they are vulnerable when electrical parameters exceed the specified limits. A cost-effective solution is proposed and described in detail.

LpR 36 | Mar/Apr 2013

Editor's Choice: The Influence of LED Emission Characteristics on the Efficiency of Lighting Systems

In general lighting, efficiency is the main focus. Under specific operation conditions, the main issue is luminous flux. The article explains why the emission behavior of the LEDs needs to be known in detail and checked against the requirements of the application.

LpR 35 | Jan/Feb 2013

Editor's Choice: DC-Grids - Challenges and Chances for LED Lighting

Recently, DC Grids were discussed at the European Center for Power Electronics (ECPE) conference. Besides fundamental issues, very specific ones like how the introduction of DC Grids affects lighting technologies and especially LED lighting were a relevant part of the program.

LpR 34 | Nov/Dec 2012

Editor's Choice: Human-Centric Lighting - Sensor Technology for Full-Spectrum Lighting Solutions

Humans are "tuned" to the natural lighting cycles of the sun, and can be equally "de-tuned", to the detriment of both health and productivity. The author discusses approaches for integrated intelligent full-spectrum solutions, and potential humancentric benefits.

LpR 33 | Sept/Oct 2012

Editor's Choice: Zhaga - Book One & Book Three Technical Compendium

The lighting industry has always worked with standard light sources that are easily interchangeable. LED retrofit lamps are also interchangeable, but they cannot unlock the full potential of this technology. The Zhaga standards aim to change that, and the selected articles will give a better understanding of Books One and Three.

LpR 32 | July/Aug 2012

Editor's Choice: Novel Approaches to Thermal Management for Power LED Packaging

Thermal management is crucial for the efficiency and reliability of LED products. For the past few decades carbon has been known for its good thermal conductivity, and different carbon based materials are available on the market. Novel approaches of using this unique material are shown.

LpR 31 | May/June 2012

Editor's Choice: LED Module Selection Considerations – The Datasheet and Beyond

The module market has grown dramatically over the past years. To make the right choice, a sound evaluation of all the modules considered is vital. The different aspects to being considered for this selection are discussed in order to guide luminaire manufacturers through the decision-making process.

LpR 30 | Mar/Apr 2012

Editor's Choice: Closing the Green Gap - A Long-Pass Dichroic Filter-Capped PC-LED

Manufacturing green LEDs with high efficacy is one of the major difficulties the LED industry is facing today. Phosphor converted LEDs can also be tuned to generate virtually any desired color; also green light. Measures that could help to make this approach an efficient and successful solution are investigated.

LpR 29 | Jan/Feb 2012

Editor's Choice: Silicon Integrated Passive Device Technology for LED Applications

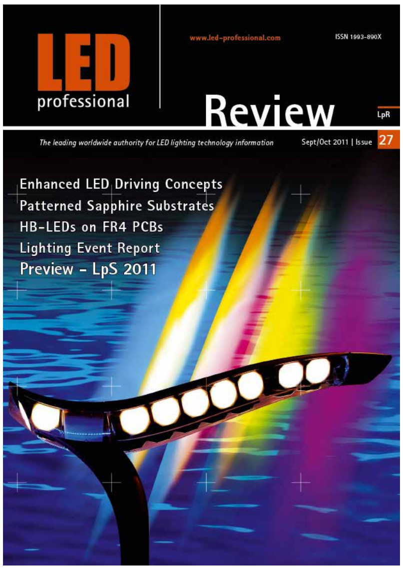
One general trend in electronics is the integration of components and functions in one single IC. Besides active components, several passive components can also be integrated. Possible reasons for using this technology, like space savings and quality issues, are discussed.

LpR 28 | Nov/Dec 2011

Editor's Choice: Print-Optical Technology – Manufacture LED Lenses by Stacking Droplets-On-Demand

3D Printing is a recognized technology in prototyping and evolving to a standard manufacturing technology. But it is possible to go one step further and to use printers as the basic tools for printing optics. Which modifications of a printer are necessary and how it works is explained.

LpR 27 | Sept/Oct 2011



Editor's Choice: Sapphire Wafer Wet Etching Versus Dry Etching

Light Extraction Efficiency (LEE) from the LED chip is one of the major topics to improve overall efficiency. Several approaches are proposed to improve LEE. A very common approach is to use dry etched Patterned Sapphire Substrates (PSS). As a more cost effective solution the new approach of wet etching is explained.

LpR 26 | July/Aug 2011

Editor's Choice: Growing GaN Epi Layers on 200 mm Silicon Substrates for LED Applications

Current LED manufacturing is primarily based on GaN-on-sapphire technology on 50 mm and 100 mm substrates. To significantly lower manufacturing costs, GaN-on-Si technology on 200 mm wafers is proposed. The current status of this disruptive approach is discussed.

LpR 25 | May/June 2011

Editor's Choice: Thermal Management of LED Lamps

Thermal management is crucial for all LED systems, but especially tricky in replacement applications. It is shown what measures can be taken to fulfill the requirements for LED replacement lamps, and which of these measures have the greatest impact.

LpR 24 | Mar/Apr 2011

Editor's Choice: Cooling High Power LEDs

Sufficient LED cooling is mandatory for LED lighting systems, but to come to an appropriate solution is often quite difficult. The article explains how to develop a cooling solution based on an independent analysis approach, i.e., analytical, experimental and computational, that provides the designer with a high degree of confidence.

LpR 23 | Jan/Feb 2011

Editor's Choice: Intelligent Lighting (Part II) - From Definition to Implementation

It seems to be very desirable to benefit from intelligent lighting systems, but the implementation is often not easy. The author explains how different features can be implemented with different levels of complexity, depending on the location and the requirements of the application.

LpR 22 | Nov/Dec 2010

Editor's Choice: Intelligent Lighting (Part I) - From Definition to Implementation

It is very compelling to install intelligent lighting systems, but finding the right setup is often difficult. The article compares disruptive proprietary solutions to established standard technologies and gives advice for selecting the right features and communication methods for different applications.

LpR 21 | Sept/Oct 2010

Editor's Choice: How Much Store Should the Lighting Industry Set by the ANSI Standard for LED Chromaticity

In the field of lighting, ANSI standards cover several different aspects of luminaires, and are not only concerned with LED lights. The author discusses whether one can take an LED manufacturer's statement of "compliance with ANSI" as a guarantee of high-quality light output under all conditions.

LpR 20 | July / Aug 2010

Editor's Choice: LED Failure Modes and Methods for Analysis

LED's promise a high reliability, and a lifetime exceeding 50,000 hours. Poor workmanship in manufacturing and unfavorable operational conditions may reduce the reliability significantly. The Objective of this article is to provide an overview of state of the art techniques in LED-Failure analysis.

LpR 19 | May / June 2010

Editor's Choice: Incandescent Replacement Lamps and Health

CFL and LED lamps have a larger blue component than red component. The author compares the different light sources and discusses whether general domestic evening use of these lamps can disturb our natural rhythm of hormone metabolism and therefore have negative consequences on our natural body rhythm and our health.

LpR 18 | Mar/Apr 2010

Editor's Choice: High Quality GaN Substrates for Modern LED Technology

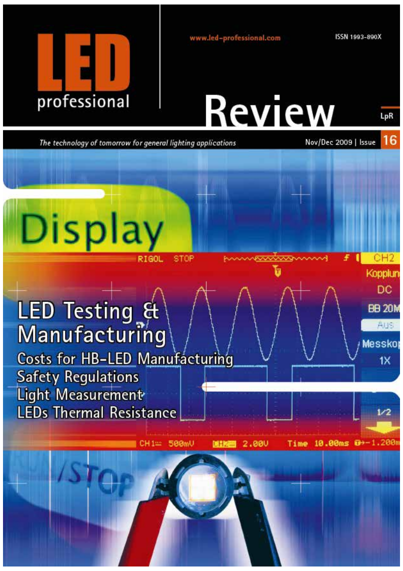
GaN templates are usually delivered on foreign substrates possessing high lattice mismatch with respect to GaN layers. An ultimate necessity in the developing of effective and low-cost recipes for low threading dislocations density GaN template manufacturing is evident. An effective new approach is described.

LpR 17 | Jan/Feb 2010

Editor's Choice: Thermally Activated Degradation of Phosphor-Converted White LEDs

The increasing performances and long lifetime of High Brightness LEDs are still limited by the high temperatures involved. Two different tests have been carried out and the impact of high temperatures has been evaluated. A detailed picture of the main degradation mechanisms is providedl.

LpR 16 | Nov / Dec 2009



Editor's Choice: A Comparison of High Level European and U.S. Product Safety Requirements

It is challenging for LED lighting product manufacturers getting new product designs launched in time. Meeting the mandatory regulatory requirements of all targeted countries can easily be overlooked. The article helps design safety regulation compliant products for both the EU and US market places.

LpR 15 | Sept / Oct 2009

Editor's Choice: Primary and Secondary Optic Materials - LED Luminaire Performance and Lifetime

Given that the LED luminaire is a system, it is important to recognize all aspects of the system that can affect or limit lifetime. The article highlights the fact that effects of current density and current spreading as well as transmission degradation of optics materials have been largely overlooked.

LpR 14 | July/Aug 2009

Editor's Choice: Quantum Dots in LED Lighting - Improving Color Quality Without Sacrificing Efficiency

Advances in the development and application of light-emitting quantum dot based materials address color quality and efficiency concerns. It is described how quantum dot technology is being applied to deliver step-change improvements in power efficiency and color quality in LED lighting solutions.

LpR 13 | May/June 2009

Editor's Choice: On the Standardization of Thermal Characterization of LEDs

The junction temperature (T_J) of an LED is not just a performance indicator of the thermal design but also plays a major role in lighting design since many properties of the light output depend on the absolute T_J. Interactions and mechanisms are discussed and explained. A proposal for action is formulated.

LpR 12 | March / April 2009

Editor's Choice: The Future of LED Illuminators

LEDs as a new technology are calling for new technical approaches. Technologies are proposed to enable the design and manufacture of illumination systems with increased efficiency, flux, radiance, controllability, reliability, durability, viewability, and design freedom and with reduced cost, mass, volume, and thickness.

LpR 11 | Jan/ Feb 2009

Editor's Choice: Off-Line LED Control Circuit

The driver electronics is crucial for the overall performance and reliability of LED lighting systems. Resonant mode topologies offer many benefits over traditional buck, boost and flyback solutions which are usually applied in LED driver designs. Results from an experimental setup using a fluorescent lamp driver IC are disclosed.

LpR 10 | Nov/Dec 2008

Editor's Choice: LED Lighting Technology Fundamentals and Measurement Guidelines

Improvements in solid state lighting efficiency, light output and quality have been remarkable. Nevertheless, many fundamental technology understandings still need to become more ubiquitous. SSL efficacy limits, efficacy and CRI tradeoffs, and technologies for increasing efficacy are discussed.

LpR 09 | Sept/Oct 2008

Editor's Choice: Review of SMS Design Methods and Real World Applications

Free form optics have proven to be the best suitable and preferred optical solutions for LEDs. Their optical design can be done in different ways.The most advanced 2D and 3D Simultaneous Multiple Surfaces (SMS) design method is proposed to generate novel optical solutions like ultra-compact LED collimators to meet real world problems.

LpR 08 | July/Aug 2008

Editor's Choice: Increasing Light Extraction Efficiency of GaN LED Chips

In the current stage of development, improving the efficiency of LEDs is urgent. Probably the most serious limitation is the low extraction efficiency due to total internal reflection between the GaN-sapphire interface. By formulating technical contradictions (using TRIZ), 30 fresh ideas were generated, and 3 of them are evaluated.

LpR 07 | May/June 2008

Editor's Choice: An In-Depth Look at Active Cooling Thermal Management: Synthetic Jet Technology

Innovation in LED lighting design is being greatly impacted by innovation in thermal management. The so-called Synthetic Jet Technology is proposed as a low noise, efficient active cooling method. It is explained how it works and how to apply it in practice.

LpR 06 | Mar/Apr 2008

Editor's Choice: Discontent Led to Lumiramic Phosphor Technology

Among the many problems faced by developers of incandescent technology were short lifetimes, fragile materials, discoloration of the glass bulbs, cost, and so forth; similar to today's LEDs. The Lumiramic Phosphor Technology is proposed to solve one of these problems, delivering better consistency and uniformity levels of white light.

LpR 05 | Jan/Feb 2008

Editor's Choice: White Light LED Technology with Increased Efficiency and Variable CCT

There is a significant tradeoff between LED efficiency, CCT and CRI. PI-LED, a new technology, promises color tunable lighting between 2700 K and 6500 K with high CRI and high efficiency. What it is, how it works, and which performance this new approach offers is disclosed.

LpR 04 | Nov/Dec 2007

Editor's Choice: Direct Copper Bonded Ceramic Substrates for Use with Power LEDs

The increase in power density for packaged LEDs led to the need for substrate materials that show an improved thermal conductivity and reliability. Direct copper bonded (DCB) ceramic substrates is one option. It is explained how it is produced, how it is used, and which properties it has.

LpR 03 | Sept/Oct 2007

Editor's Choice: LED Data Sheet Comparisons

Auspicious values for luminous flux, efficacy and other parameters are highlighted in data sheets. The article compares different products and figures out the values that could be expected if the data were taken under more realistic conditions, based on the given information in the data sheets.

LpR 02 | June/July 2007

Editor's Choice: Color Compensation - LED Technology for Color Constant RGB Color Mixing Luminaires

Lighting designers have always used colored light to add emphasis or provide atmospheric effects. Superficially speaking, colored LEDs seem to make the task simpler and more colorful. But for satisfactory results, a compensation of the deviations in luminous flux and hue is necessary.

LpR 01 | Mar/Apr 2007

Editor's Choice: White LEDs and Modules for General Lighting

LEDs have already surpassed incandescent light sources in efficiency. In addition to other issues, an efficiency of 50 to 100 lm/W is needed to materialize significant energy savings. Costs also have to be lowered. The article shows the significant advantages of COB technology over SMD LEDs.

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Cover-page

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Product: Philips AmbientLED

Residential luminaire with a Gen I Philips AmbientLED Replacement bulb

Next LpR

DESIGN & ENGINEERING
Issue 51 - Sept/Oct 2015 - Short Overview

STANDARDIZATION

Measurement Uncertainty and Conformity

The availability of reliable and accurate photometric data for LED devices is a basic requirement for designing good lighting systems, evaluating performance of products and comparing data between different laboratories. The article will explain how to measure the products and how to interpret data regarding measurement uncertainties and manufacturing tolerances according the new ISO/IEC Guide (Guide 98-4:2012). Furthermore, the author explains how to implement these guidelines in the industrial practice. ■

TECHNOLOGIES

Chip Arrays in SMD Packages - A New Class of LEDs

Recently, several companies launched products that can commonly be referred to as a new class of LEDs – Chip Arrays in SMD packages. The article gives an overview of the benefits and drawbacks of these packages in LED retrofit lamps as well as in different types of luminaires. Use-cases illustrate the huge benefits that CAS can generate when used both in spot lights as well as in omnidirectional light sources. It also approaches lifetime and reliability concerns and shows how the right choice of products and a good thermal design can satisfy even high demands. ■

RESEARCH

"Best Papers" at LpS 2014: Al_2O_3 Coated Europium-Activated Phosphor for use in COB Technology

Yellow-red emitting phosphors are important for high quality white light generation with LEDs. Unfortunately, these phosphors are often less efficient or degrade relatively fast. To improve material properties, a method to prepare $CaAlSiN_3$:Eu^{2+} phosphor was investigated and different properties, including luminescence, were determined. ■

SPECIAL

Latest Zhaga Consortium Activities

In a series of articles, Zhaga members will explain how the organization is making progress towards its aim of standardizing LED light engines and associated components, and simplifying LED luminaire design and manufacturing.

- New Books under development
- COB specification
- Thermal interface
- Light-emitting surface (LES)
- Driver-module interface (DMI)

A bundled series of comprehensive articles will disclose details and technical guidelines for the latest Zhaga Books. ■

subject to change

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