www.ledsmagazine.com Technology and applications of light emitting diodes

LEDs MAGAZINE

LEDs Magazine Review

Issue 8 August 2006

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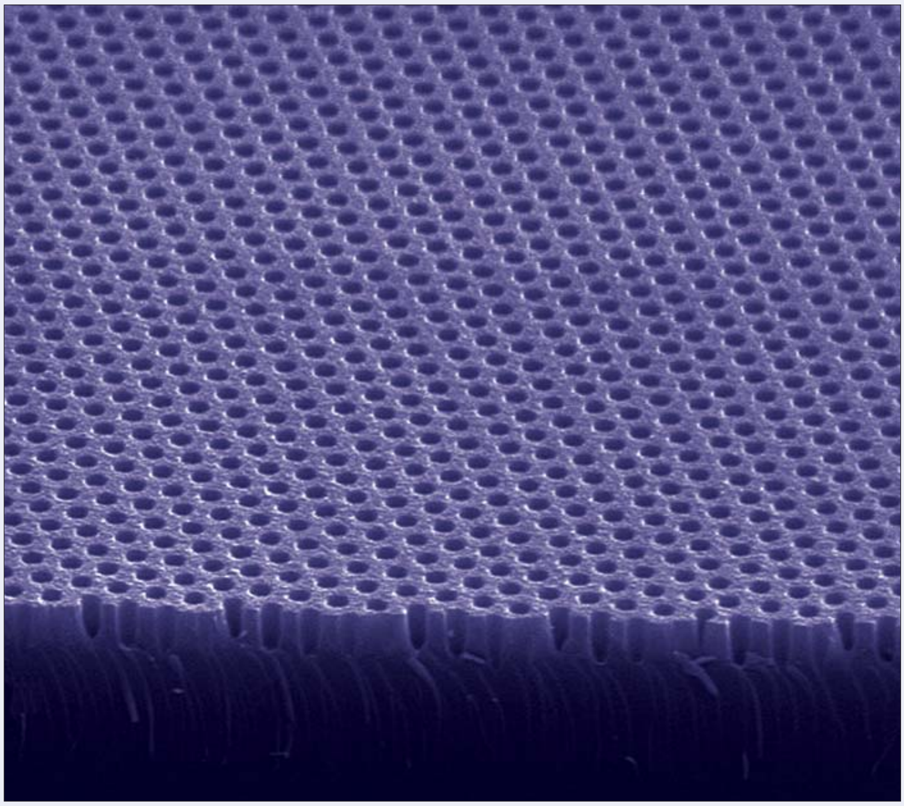
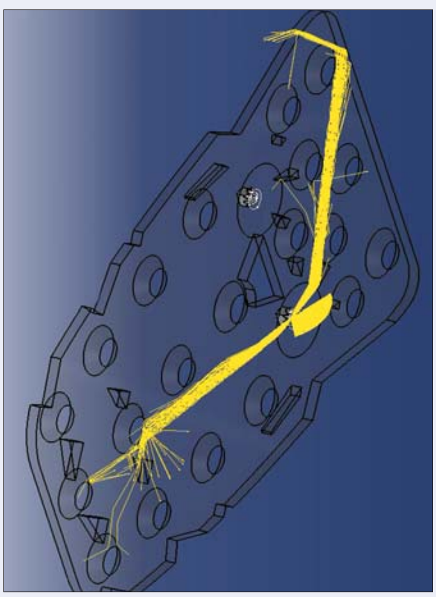
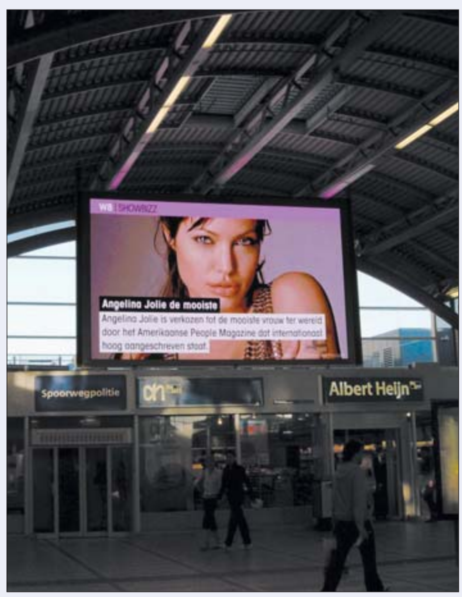
LEDs Magazine is published by IOP Publishing Ltd and Cabot Media Ltd. Contact address: Institute of Physics Publishing, Dirac House, Temple Back, Bristol BS1 6BE, UK.



Photonic crystals enhance the extraction efficiency of LEDs and place the light where it's required. **p21**



Optical design software accelerates the design process for LED-based systems. **p27**



Advertising billboard networks are using LED displays, as well as competing technologies. **p29**

Light it.

with

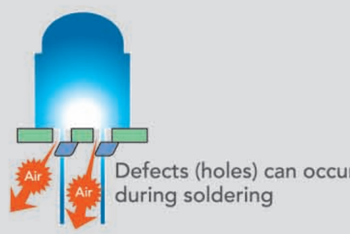
Ultra High Bright LEDs

The Only LED Lamps with a Pressure Release Structure (SLI / R-343 Series).

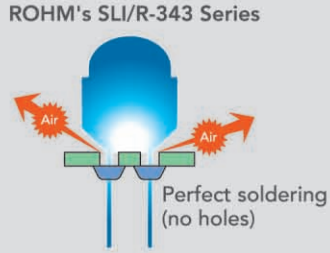
No Retouch Soldering

ROHM's pressure release structure prevents pressure build-up during the soldering process when the LED is mounted on the PCB.

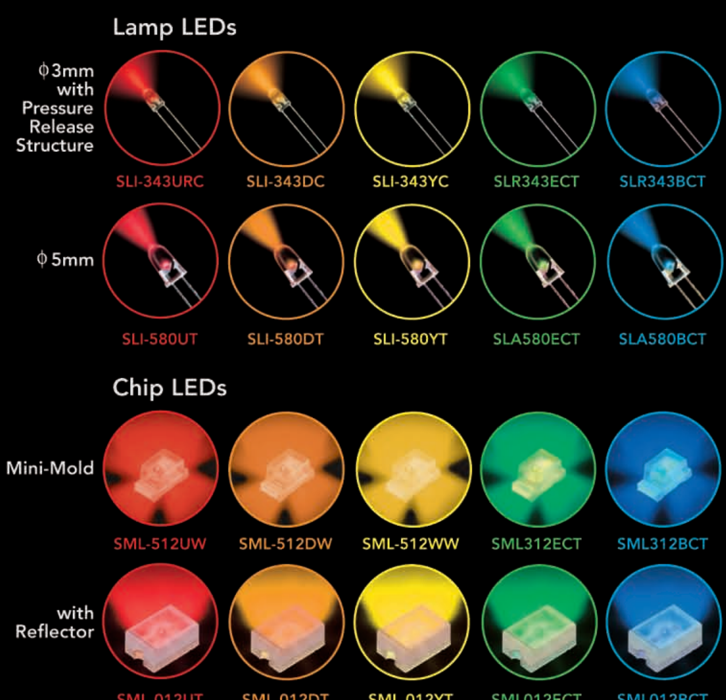
Conventional Product



ROHM's SLI/R-343 Series



Pick a color. ROHM's ultra high bright LEDs are available in many luminous colors.



Wide Directivity

ROHM's ϕ3mm LEDs feature a directivity equivalent to that of ϕ5mm LEDs (luminous intensity half-power viewing angle approximately 40°).

Many Luminous Colors

ROHM offers an LED lineup in a variety of luminous colors using both AlGaInP (a proprietary compound) and InGaN.

A Broad Lineup of LEDs

- Right angle chip LEDs
- Reverse mount chip LEDs
- Low current chip LEDs (ideal for portables)
- Dual color chip LEDs
- LED lamps with pressure release structure
- Direct mount LED lamps

Excellence in Electronics

ROHM

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MOBILE APPLIANCES

Nokia predicts increasing LED usage in mobile phones

The number of LEDs that are used in mobile phones is likely to increase as more functionality is added, says Barry Rowland, a technology specialist for Nokia in the field of LEDs and LED power management. Speaking at PIRA-Intertech's conference, "The Future of LEDs", in late June, Rowland said that camera flash using LEDs is going to be a big market, and that added functionality using LEDs is on the increase.

"Handsets are likely to become more user-configurable," said Rowland. "As one example, RGB LEDs can allow the user to change the keypad backlight color." Another example is using different LED colors to indicate the arrival of SMS or email messages, or to differentiate between callers.

Other speakers including Asif Anwar of market research firm Strategy Analytics said that the overall market for LEDs in phones will be roughly flat, mainly owing to declining prices counteracting the growth in segments such as flash. Rowland did not disagree with these views, saying, "As a major buyer, Nokia is pushing costs down." The cost of using LEDs takes into account drivers, light-guiding and many other factors, as well as the LED price. However, said Rowland, "lower LED pricing means that Nokia can use more LEDs for new functions."

Power consumption is always a key issue in mobile handsets. Improvements in LED brightness, which have continued despite predictions that they would level off, translate to lower power consumption for a given display brightness. The introduction of blue LEDs with forward voltages as low as 3 V means that these devices can be run from a battery without a boost converter.

Rowland estimated that LEDs will continue to become more efficient, and that lm/W values have increased by a factor of 10 in the last 10 years. This helps reduce the power drain and ease thermal management issues. "Since none of the functions are 100% efficient, we always have to consider how to get the heat out," he said.

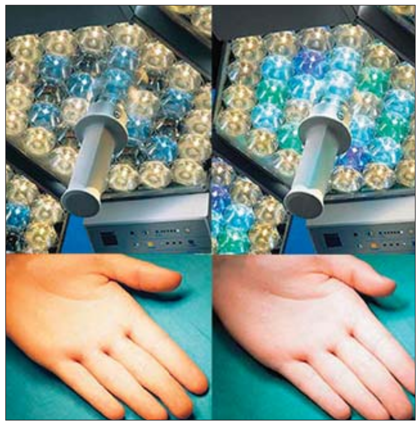
Display backlighting could benefit from using RGB LEDs to increase the color gamut and allow dynamic adjustment of the white point, for example under different ambient lighting conditions. However, there are significant challenges in realizing accurate white-point control, for example the wide variation in red LED performance with temperature.

For keypad backlighting, a major trend is the introduction of very small and thin LEDs measuring 1 × 0.5 mm. "In a few years' time we will see 'paper-thin' LEDs with dimensions of 0.1 mm," said Rowland. "We'll be able to put them in places we never thought of before." As well as leading to more placement and light-guide construction options, this will cancel out the main advantage of electroluminescence technology for keypads, i.e. extreme thinness.

In the flash area, Rowland forecast a move from sub-2 W LEDs and drivers to the 4 W level. "I agree this is going to be a big market [for LEDs]," he said. "Customers have higher and higher expectations from their high-pixel-count cameras." LED improvements and more sophisticated optics are resulting in large increases in delivered lux levels. However, said Rowland, the drive levels may become limited by battery technology and could require the use of supercapacitors. Xenon flash is viewed as providing better light output and color rendering, but there are packaging issues. Another advantage of LEDs is that they can also operate in continuous mode for video filming.

MEDICAL

Trumpf's adjustable light helps surgeons control the contrast



Trumpf Medizin Systeme has developed a surgical light that contains 184 white and colored LEDs, allowing the surgical team to adjust the light's color temperature and to maintain good contrast under different conditions.

- More details: www.ledsmagazine.com/articles/news/3/8/4

INDUSTRY ORGANIZATIONS

DOE, IESNA work together on solid-state lighting standards

The US Department of Energy (DOE) and the Illuminating Engineering Society of North America (www.iesna.org) are working together to develop industry metrics and standards for solid-state lighting (SSL) technology. Such metrics will be one of the foundations for bringing SSL into Energy Star, a voluntary labeling program designed to identify and promote energy-efficient products (see below).

The agreement outlines five broad goals for joint DOE–IESNA efforts, including developing DOE efficiency standards and IESNA standards and procedures; developing guides and procedures to assist the lighting community in the photometric measurement of SSL devices, and providing consistency and uniformity in photometric reports; and developing standards that include a focus on energy-conservation strategies to benefit design professionals and users.

IESNA is a recognized technical authority on illumination, and communicates information on all aspects of good lighting practice to its members, the lighting community and consumers. IESNA correlates research, investigations, and discussions to develop consensus-based lighting recommendations.

The relationship with IESNA is part of a wider commitment by the DOE to develop industry standards. A DOE workshop in March 2006 provided a forum for greater co-operation and coordination among standards organizations, including IESNA, National Institute of Standards and Technology (NIST), National Electrical Manufacturers Association (NEMA), American National Standards Institute (ANSI), Underwriters Laboratories (UL), International Electrotechnical Commission (IEC), International Commission on Illumination (CIE) and Canadian Standards Association (CSA). The DOE continues to work with these organizations to align their individual priorities and schedules, and maintain a master roadmap of development activities.

SSL partnership collaborates on draft Energy Star criteria

The DOE is also working closely with the Next Generation Lighting Industry Alliance (NGLIA) to develop draft Energy Star criteria for white

LED-based lighting, as part of its activities to support the commercialization of SSL products. The NGLIA (www.nglia.org) is an industry body that promotes the understanding, implementation and adoption of semiconductor light sources in specialty and general lighting systems.

"Over the past several months, we have worked jointly towards the first draft of an Energy Star specification for LED products," says Kyle Pitsor, NGLIA Administrator. Following three months of public review and comment, final criteria are scheduled to be issued in October 2006.

Pitsor says that this is a difficult and wide-ranging task, which is being driven in part by a determination to protect the market from poor-quality products that could spoil customer perception of the technology. "There is a very natural synergy between the DOE's R&D program and Energy Star criteria, since the research program plus the DOE/NGLIA technology roadmaps give a good view of what is and what is not likely to be possible in the coming years," he says.

In the lighting area, Energy Star is currently focused on compact fluorescent lamps, although LEDs are strongly emphasized for Energy Star-rated traffic signals and exit signs.

Energy Star criteria for SSL will focus on near-term niche applications and will be used for several years, helping consumers recognize energy-efficient, high-performance SSL products on the market. Additional DOE Energy Star criteria will be developed as the market and products evolve.

OLEDS

Konica Minolta's latest white OLEDs hit 64 lm/W mark

In July, the Japanese company Konica Minolta reported a white OLED with a luminous efficacy of 64 lm/W and a luminance of 1000 cd/m^2, as well as an expected time to half brightness of 10,000 hours. The company intends to focus on lighting applications, but will have to make lifetime improvements if the OLEDs are to be built into semi-permanent wall or ceiling panels, as distinct from replaceable lamps (compact fluorescent lamps typically last for about 6000 hours).

In Europe, a joint research effort between Philips Lighting, Philips Research and Novaled has developed a white OLED with an efficacy of 32 lm/W at a brightness of 1000 cd/m^2. The device had color coordinates of (0.47, 0.45) and a CRI of 88.

The same device structure had a lifetime of more than 20,000 hours, which the companies described as a major achievement for future commercialization of OLED technology for lighting applications.

Osram Opto Semiconductors says that it plans to intensify its R&D work on OLEDs with the aim of applying this technology to general illumination, while at the same time expanding its existing business in OLED displays. The company will continue to develop polymer-based solutions for displays, and is now also focusing on small-molecule technology for illumination applications. Initial research findings indicate that Osram's white OLEDs can achieve a luminous efficacy of up to 25 lm/W, while at brightness levels suitable for general lighting the efficacy is18 lm/W.

At the SPIE conference in August, Universal Display Corporation announced that its white OLED source had demonstrated 31 lm/W efficacy with an external quantum efficiency of 29% at a luminance of 850 cd/m^2. The 5 × 5 cm panel had a warm white color with CIE coordinates of (0.37, 0.36).

- More details: www.ledsmagazine.com/articles/features/1/4/9

ARCHITECTURAL LIGHTING

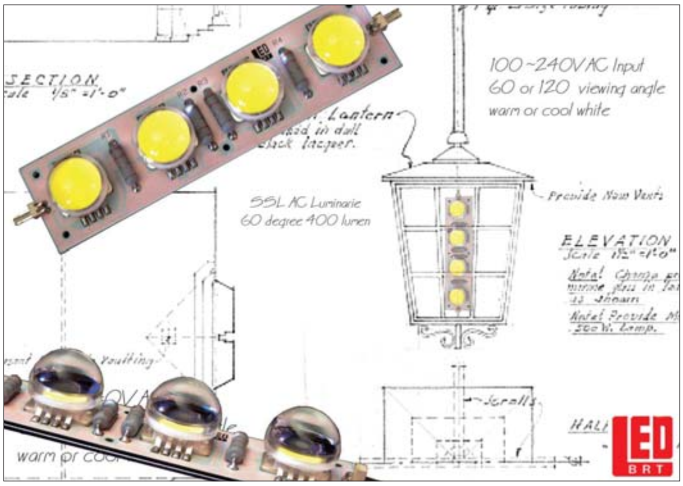
Ancient Roman aqueduct gets the LED lighting treatment

LED PixelLine products from James Thomas Engineering have illuminated the ancient Le Pont du Gard aqueduct in Southern France.

Other articles on the ARCHITECTURAL LIGHTING channel of our website (www.ledsmagazine.com/articles/features/1/5/2) include:
- Kevan Shaw Lighting Design plans to use a skin of addressable LED elements to light the Sport City Tower in Qatar.
- Several LED-related projects were among the winners of the International Association of Lighting Designers (IALD) Design Awards.
- A news blog on the *Wired* website highlights a number of impressive examples where LEDs have been used in architecture.

AC LEDS

AC supply drives American Bright LED lighting module



American Bright Optoelectronics has introduced a new LED lighting module powered by a custom AC driver from Lynk Labs. The BWCL series can accept an AC input of 3–1000 V, and American Bright says that this affords the designer the greatest possible freedom to design fixtures bases on desired aesthetics rather than packaging of compatible drivers. The light engine comprises four NovaBrite series LEDs coupled to an innovative sandwich of PCBs, with standard FR4 material bonded to a 2 mm aluminum heatsink PCB. The individual NovaBrite modules are then mechanically bonded through both the FR4 and the metal-core PCB to ensure maximum thermal conductivity and efficiency.

● More details: www.ledsmagazine.com/articles/news/3/7/26

DEVICES

Cree sets new standard with 131 lm/W white LED at 20 mA

Cree, a leading US-based LED manufacturer, has set a new benchmark for white LED efficacy with an R&D result of 131 lm/W. The white phosphor-converted device was built around a small-area LED chip (less than 0.3 mm square) and was driven at 20 mA. The correlated color temperature was 6027 K and the results were confirmed by the US National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland.

This is an R&D result for a prototype device and does not reflect the performance of current production devices, although it certainly points the way to commercial LEDs in the near future with efficacies exceeding 100 lm/W. Both Cree and Nichia have previously announced R&D results for white LEDs of 100 lm/W.

Fritz Morgan, CTO of Color Kinetics, a Cree customer, said: "Technical advancements at the component level are critical to growing the emerging white LED lighting space. Cree's results speak to the exciting developments underway that will enable new white light applications and subsequently facilitate market adoption."

The prototype white LEDs were fabricated using Cree EZBright LED chips operating at 20 mA. EZBright chips, typically measuring less than 0.3 × 0.3 mm, are designed to be incorporated into white LEDs that are used as backlights for LCD screens in mobile phones, as well as many other applications. Cree sells EZBright chips to external customers, rather than using them to manufacture its own white LEDs.

Cree's high-power XLamp packaged LEDs incorporate larger chips (1 × 1 mm). These devices are designed to operate at 350 mA, and consequently have lower efficacy than the smaller-chip devices. Cree's commercial white XLamp product produces 57 lm at 350 mA, with 47 lm/W efficacy, although the company is planning to release a new iteration with an efficacy exceeding 60 lm/W.

● More details: www.ledsmagazine.com/articles/news/3/6/19

PATENTS

Toyoda Gosei calls for caution regarding its LED patents

Toyoda Gosei Co Ltd, one of the world's leading LED manufacturers, has surprised the community by issuing a press release advising "the fullest caution to avoid infringement" of its patents on GaN-based LEDs.

Toyoda's rivals Nichia and Osram Opto Semiconductors have been active in recent years in pursuing companies that they believe infringe their patents, and have also publicly announced licensing agreements for their technology (see www.ledsmagazine.com/articles/features/1/8/21). However, Toyoda has kept relatively quiet, despite owning a patent portfolio that is second to none and arguably forms the basis for the entire GaN-based LED industry.

Toyoda has signed two major agreements with its rivals; an agreement with Nichia dating back to September 2002 and a more recent agreement with Philips Lumileds signed in April 2006. Toyoda says that these separate agreements allow the parties to utilize each other's LED-related patents, and also says that it licenses the use of particular LEDs as defined in individual agreements.

The Toyoda press release goes on to say that, "because the manufacture, sale or use of GaN-based semiconductor LEDs by any entity other than these may constitute infringement of Toyoda Gosei's patents, Toyoda Gosei advises the fullest caution to avoid infringement." The company says that it has filed more than 2000 patent applications related to GaN-based semiconductor LEDs, and has acquired patent rights on some 600 of these.

Details of the agreement between Nichia and Toyoda have never been made public, but there is a strong indication that Toyoda emerged in by far the strongest position, given that it had won almost all the court cases between the two companies prior to the settlement date. One suggestion is that Toyoda has the right to use Nichia's GaN-based LED patents up until the settlement date, but that the reverse is not true.

White LED-related patents

Toyoda's press release also discusses the silicate-based phosphor technology patented by Toyoda in partnership with Tridonic Optoelectronics GmbH (Austria), Leuchtstoffwerk Breitungen GmbH (Germany) and Litec GbR (Germany).

The patents cover technology for combining blue LEDs with silicate phosphors. Patent rights have been granted in Austria, the US (patents 6,809,347 and 6,943,380), Korea, Taiwan and Russia, and China will be soon added to the list.

Toyoda says that it has about 20 licensees for these patents world-

wide, but it now believes that companies other than licensees have been manufacturing and selling white LEDs using silicate phosphors. Again, the company is advising "the fullest caution" to avoid any infringement that might be taking place.

- More details: www.ledsmagazine.com/articles/news/3/8/10
- Our article on patents on page 12 discusses the rights conferred by a patent license on the licensee, and many other related issues.

REPLACEMENT LAMPS

LSG, Osram Opto develop LED-based MR-16 and R-30 lamps

Lighting Science Group Corporation (LSG), an LED-fixture manufacturer, is building its new LED-based MR-16 and R-30 lamps using Ostar Lighting LEDs from Osram Opto Semiconductors. Prototype lamps were displayed on Osram's booth at Lightfair in June. LSG's new energy-efficient lamps offer a direct alternative to the highly popular MR-16, or metalized reflector halogen lamp, currently used in the marketplace.

The company says that significant energy savings are possible when these lamps are used in industrial and commercial applications, especially in shopping malls, kiosks, museums and office complexes, where the benefit of replacing conventional lighting over hundreds of thousands of square feet can add up very quickly. The MR-16 lamp contains a single 6-chip Ostar while the R-30 version (pictured) contains three such LEDs; the hexagonal shape of the Ostar's board makes it easier to pack the LEDs close together.

- More details: www.ledsmagazine.com/articles/news/3/7/14

NATIONAL PROGRAMS

China invests millions in its solid-state lighting program

By Robert Steele, Strategies Unlimited

Saving energy and stimulating domestic LED production are key goals behind China's decision to invest around $44 million in its national solid-state lighting program. China expects to be the largest market for LEDs and solid-state lighting. A national solid-state lighting program was formally inaugurated in February 2006 as part of China's 11th Five Year Plan. Dr Ma Songde, vice-minister of science and technology, says that the growth of the hi-tech sector is key to China's future development, and that LEDs are seen as an indispensable part of that sector. Dr Ma, chair of the Governing Committee for China Solid-State Lighting, was speaking at the third annual China International Forum on Solid-State Lighting (CIFSSL) in Shenzhen in July.

Only 10% of China's GDP comes from the hi-tech sector, and 88% of that results from foreign companies located in China or from joint ventures with Chinese companies. Therefore, one goal of the national SSL program is to stimulate domestic production through public–private partnerships. Another key goal is energy savings; China consumes the most energy after the US, and its energy consumption per dollar of GDP is much higher than Japan, Europe or the US. The country has ambitious plans to quadruple its total GDP by 2015, but to only increase energy consumption by a factor of two. Lighting is a key element of energy-demand growth, especially as 14 million rural Chinese move to cities each year. The adoption of SSL will be an important element in reducing the growth of energy demand.

To address the R&D needs for SSL, China has budgeted RMB350 million ($44 million) during the 11th Five Year Plan. Participation will include more than 15 research institutions and university research labs, as well as more than 2500 companies involved in LED wafers, chips, packaging and applications. Protection of IP is a significant concern and a major element of the SSL program. Chinese companies are encouraged to file patents to protect their IP and to look for patent "gaps" where there are areas of SSL that have not yet been addressed by foreign companies, primarily in the "downstream" areas of packaging and applications.

- See www.ledsmagazine.com/articles/features/3/7/6 for the full version of this article, including a detailed discussion of patent issues.

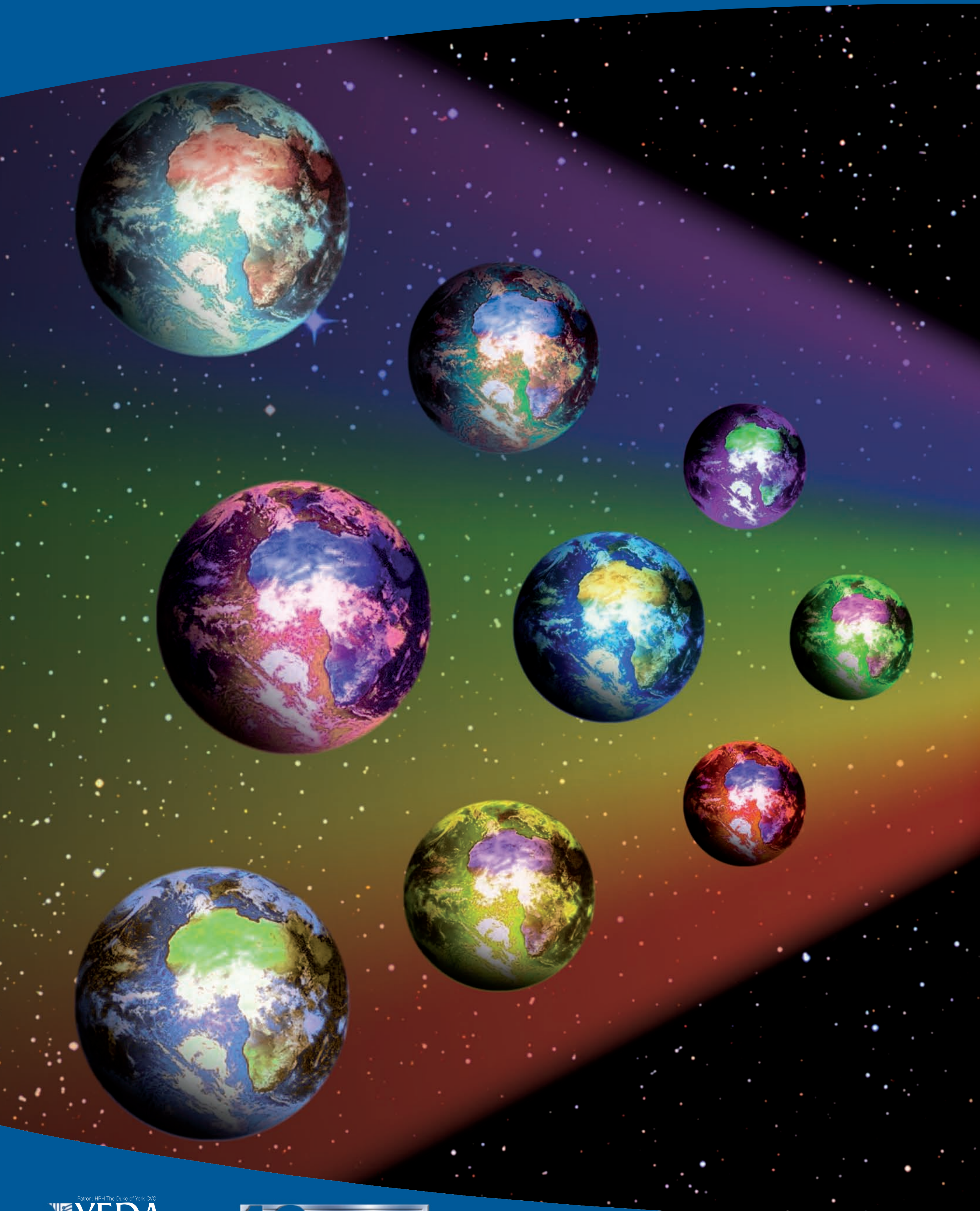
DEVICES

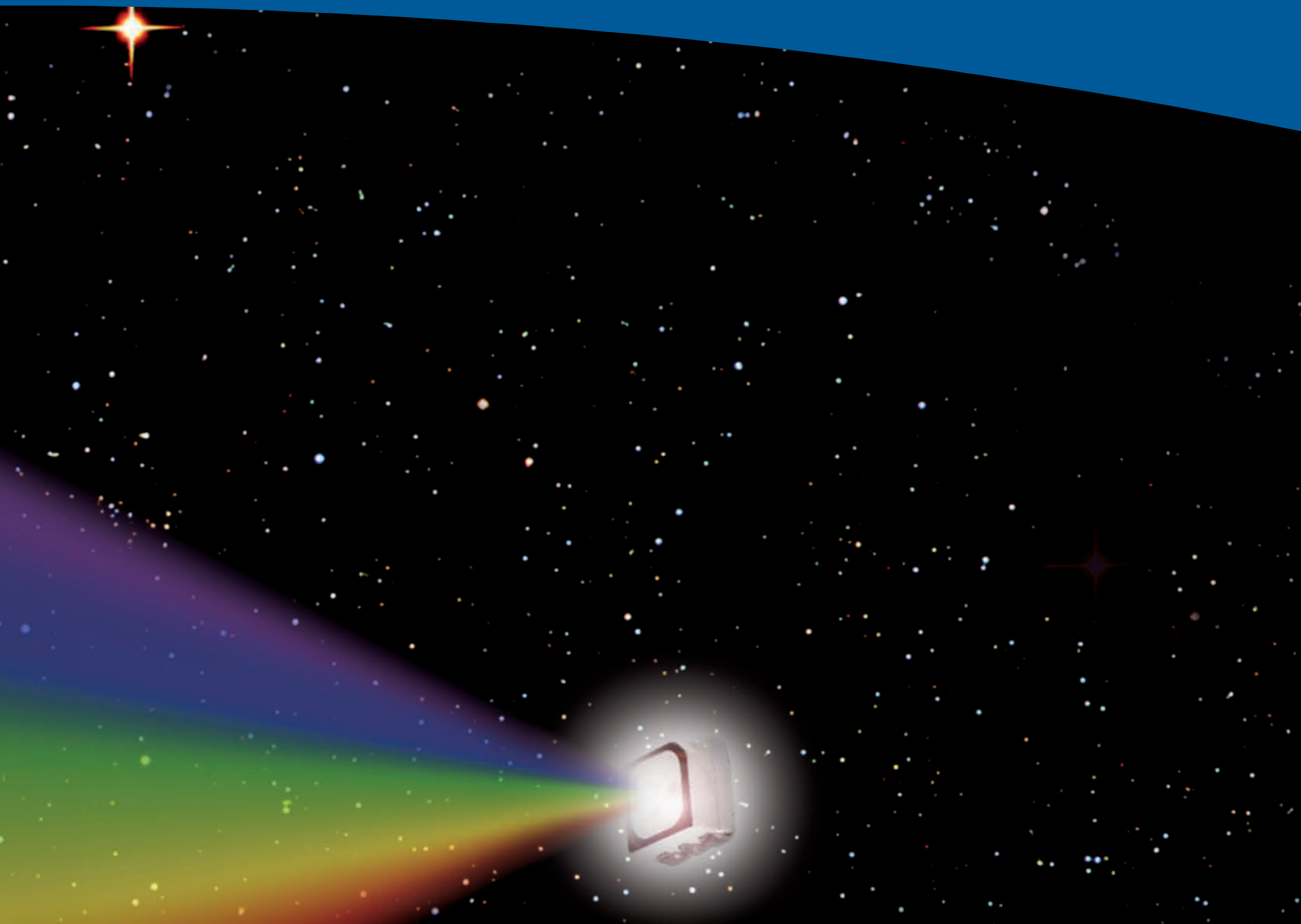
Avago joins high-power market with one-watt InGaN LEDs

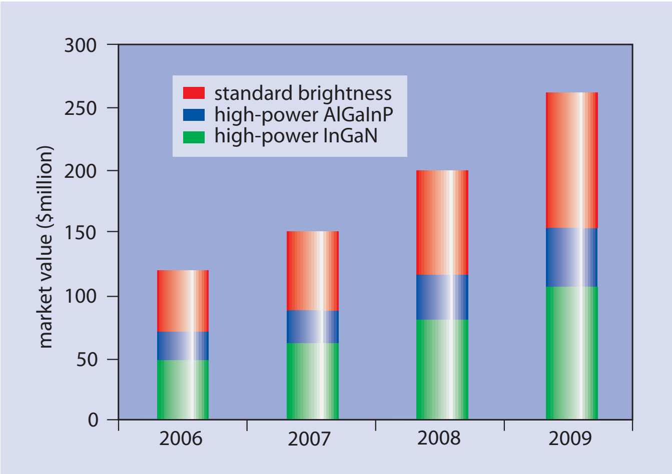
Avago Technologies has belatedly entered the high-power LED market with a new product range of InGaN-based, "one-watt" class LEDs. High-power LEDs are usually classified as devices operating from a power level of more than 0.5 W, with a drive current of more than 150 mA. Typical "one-watt" class LEDs operate at 350 mA (where the actual dissipated power is around 1.2–1.4 W) and the chip size is generally around 1 mm × 1 mm. Meanwhile, BridgeLux has just commenced production of a 1.5 mm chip, while Osram Opto is filling a gap in its product line-up with a mid-range LED operating at around 140 mA.

Avago launches one-watt LED

In June, Avago finally entered the high-power LED market with a family of InGaN-based (blue, green, white) LEDs targeting solid-state lighting (SSL) applications. The company, which was previously







Avago's estimates for the LED market for solid-state lighting in Europe. The new Avago products address the high-power InGaN segment, while existing standard-brightness products are suitable for certain mood lighting and other applications.

Agilent's semiconductor products division, was until recently restricted to servicing low-power LED segments (< 200 mW). Lumileds Lighting, the joint venture set up by Agilent and Philips and now owned by the latter company, focused on the high-power LED market space. "Now, as Avago, there are no restrictions," says Patrick Trueson, Avago's product marketing manager. "The high-power LED market is the key focus segment moving forward."

Trueson acknowledges that although Avago is quite late to a market with plenty of competition, the market has seen a rapid expansion in recent years. "It absolutely makes sense for Avago to have these products and to focus on solid-state lighting," he argues. "We have a low-profile, reliable and easy to use package, and we hope to capture 10% of the addressable market in Europe." Avago's estimates for this market are shown in the graph above.

Avago has also recently released new products in its illumination and color management (ICM) family, including RGB color sensors and controllers capable of maintaining a fixed RGB ratio over variations in time, temperature and drive conditions. Currently these are targeted at the display backlighting market. However, in future, Trueson says that Avago will combine new state-of-the-art high-power (20 W) RGB light sources with its ICM products to offer closed-loop systems that can maintain precise color temperatures in SSL applications.

The current offering includes InGaN-based devices only, but AlGaInP products will be available around the end of this year. "We're currently working closely with our strategic partners to qualify the industry's best AlInGaP chips into our PowerLED packages," says Trueson.

Avago's package uses silicone encapsulation and has a low thermal resistance of 10 °C/W, both factors that extend the LED lifetime. "Good thermal management and silicone encapsulation, as well as using high-quality dies, leads to a better lifetime than other approaches." Avago quotes a lifetime of 50,000 hours to 30% degradation at 350 mA at an ambient temperature of 25 °C.

The package is compatible with IR reflow soldering and standard SMT process lines, says Trueson, and has a moisture sensitivity level (MSL) of 2a, which means that the LED can last for four weeks after the sealed package is opened on the factory floor. "Some LEDs have to be soldered after 72 hours, or a week, otherwise they have to be re-baked. We see this as a big advantage." Handling of the packages is also made easier by the in-built zener diode that provides 16 kV electrostatic discharge (ESD) protection (class 3b). The devices are also ROHS compliant and Pb-free. In terms of output, the LEDs have a typical total luminous flux of 40 lm in green, 10 lm in blue and 35 lm in white at 350 mA forward current.

- More details: www.ledsmagazine.com/press/12713

Osram Opto's Advanced Power TopLED

Osram Opto Semiconductors' new Advanced Power TopLED sits in what some describe as the "high-current" regime, above "standard" HB-LEDs operating at around 20 mA but below "high-power" devices in terms of drive current and light output. At 140 mA, the device has an output of 19 lm in green and amber, 15 lm in white and red, 14 lm in yellow and 5 lm in blue. This is 50% more than previous versions. The surface-mount package is designed for applications such as illuminated signage and effect lighting.

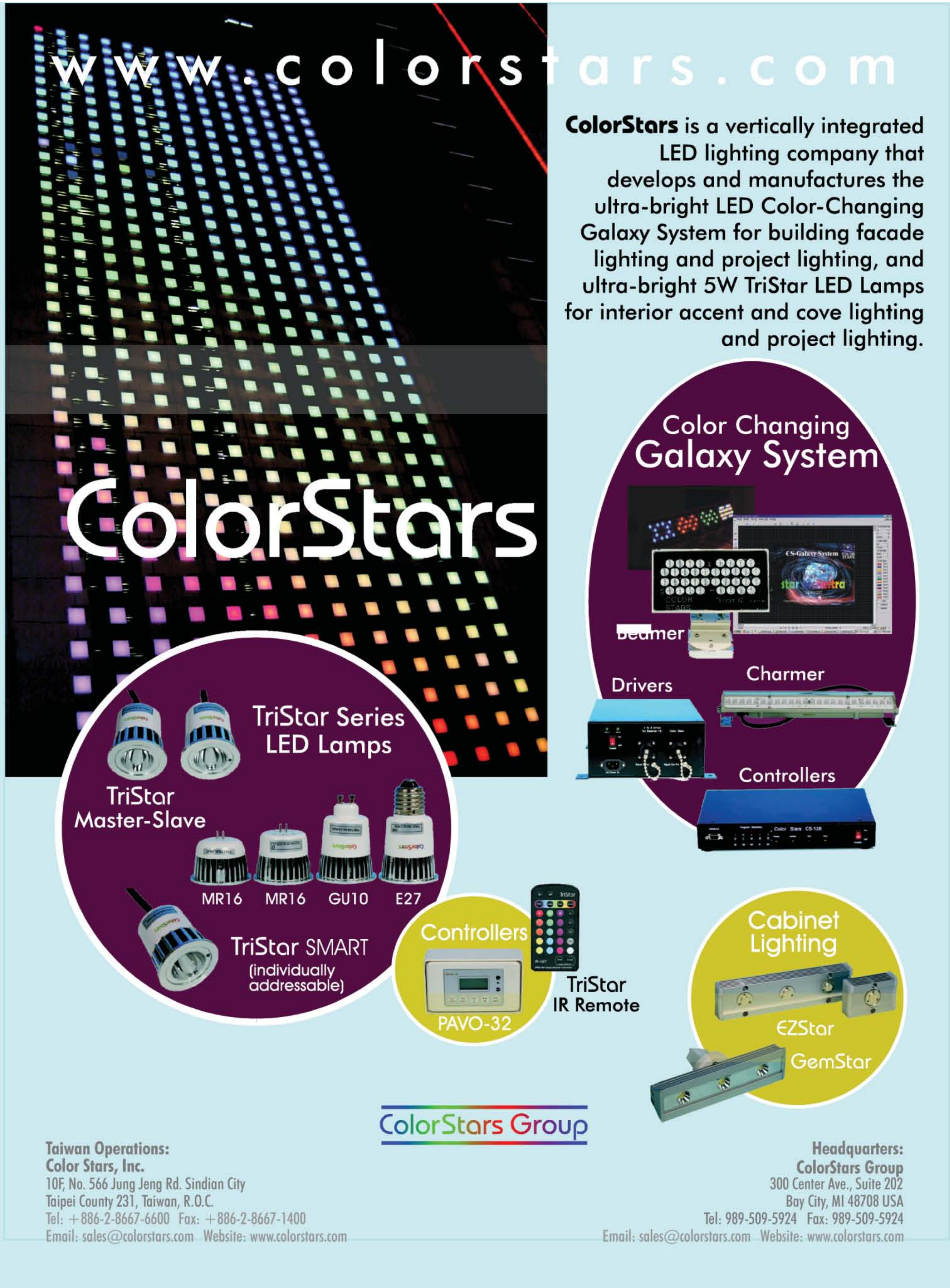
- More details: www.ledsmagazine.com/press/13026

BridgeLux unveils 1.5 mm LED chips

BridgeLux, a US-based fables supplier of high-power LED chips, has introduced the KO family of LEDs, including what it describes as the only 60-mil (1.5 mm) chip available in production volumes today. BridgeLux says that the 60-mil KO chip, available in blue, cyan and green, can support up to 1.2 A drive current. When packaged with phosphors, the resulting white LED should generate 140 lm, depending upon packaging design. Smaller blue chips are also available. The entire family is designed to stand up to 150 °C junction temperatures and 40% higher drive currents than commonly found for similarly sized devices.

"The development objective with the KO series was to reduce the input voltage while increasing the overall light extraction," said BridgeLux CEO Robert Walker. "We've nicknamed the 60-mil KO the 'bulb buster' since we have something here that can really begin to challenge traditional lighting solutions in general-purpose illumination."

- More details: www.ledsmagazine.com/articles/news/3/7/8



www.colorstars.com
ColorStars is a vertically integrated LED lighting company that develops and manufactures the ultra-bright LED Color-Changing Galaxy System for building facade lighting and project lighting, and ultra-bright 5W TriStar LED Lamps for interior accent and cove lighting and project lighting.
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MR16
GU10
E27
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Email: sales@colorstars.com Website: www.colorstars.com

Patents – are they a blessing or a curse for the LED industry?

The patent system is intended to encourage invention and innovation, and should benefit the LED industry, provided that the need for litigation can be alleviated by licensing and avoiding infringement, say **Alice Martin** and **John Wappel** of Barnes & Thornburg, LLP.

When patent disputes occur, such as in the LED industry recently, questions arise about whether patenting helps or hurts individual businesses and the industry as a whole. To form educated answers on issues involving patents and patent litigation, an understanding of the mechanics of obtaining and enforcing patents is helpful.

What is a patent?

Patents are one form of protection for intellectual property that includes compositions of matter (e.g. products such as chemicals), methods (e.g. how to produce a lighting effect, business methods), apparatus (e.g. lights, winches) and computer software.

United States patents are documents issued by the US government granting exclusive rights to inventors over their inventions. Patents have three basic parts: the specification, which describes what the invention is, and how to make and use it; the drawings, if required, which depict one or more embodiments, or variations, of the invention; and the claims, which set the boundaries of what is protected, i.e. define the "claimed invention".

This distinction is important because some undue concern is generated surrounding the misconception that the items described in the specification are "covered" by the patent. However, it is the claims that determine what subject matter is protected. Unless subject matter is covered in the claims of an issued patent, it is not protected.

While the specification supports and explains the claims, the exclusive rights in the invention are defined by the claims. Parts of the specification not appearing as claimed elements cannot be enforced.

Claims are generally written in two ways: independent form or dependent form. An independent claim is just that, it stands on its own and defines a complete invention having a discrete set of elements. Dependent claims refer to a previous claim, either an independent claim or another dependent claim, and are a short-hand way of adding additional elements. The elements covered in a dependent claim include the elements listed in that claim plus the elements in the claim from which the dependent claim refers.

What is a patentable invention?

Claims are patentable if they delineate an invention that is novel, useful and non-obvious based on the claim elements considered as a whole. To satisfy the novelty criterion, there must be no public disclosure, publication, presentation, use, sale or offer to sell, by the inventor or others, of the invention as delineated in the elements of the claims. (There are some exceptions and grace periods.)

A claim is novel if there is no "prior art" that discloses the invention. (Prior art includes publications, patents and so forth that precede an invention.) Even one novel element in a claim should satisfy the novelty requirement. Most inventions are combinations of existing elements (bolts, screws, gears, etc.) arranged in a novel way.

Improvements to an existing product, method or apparatus may be patentable even over existing patents. A simple example is a patented pencil having the elements of (a) a graphite core and (b) a protective sheath positioned about the graphite core. A patentable improvement could be adding element (c) an eraser, to one end of the pencil, assuming that no one had done that before. Despite the new pencil/eraser combination being patentable, it would still infringe the first patent that required only a graphite core and a protective sheath, because the new pencil/eraser combination has each of the claimed elements of the first patent.

The patent system strikes a balance by granting exclusive rights to inventors for a limited period of time in exchange for the inventor's knowledge and technical expertise.

In such cases, there is incentive to cross-license. For instance, using the pencil example, the inventor of the "improved pencil" would have an incentive to seek a license from the owner of the prior-art patent so the inventor could market his new pencil. The owner of the prior-art patent, seeing the improvement and the likelihood that his customers will want the improved pencil, would have an incentive to seek a license from the inventor on the patented improvement so that he can continue in the pencil market.

Some other patentability requirements include "enablement" – the specification must teach how to practice the invention "without undue experimentation" and "written description" proving the inventor "possessed" the invention. To satisfy the enablement and written description requirements, a patent must contain a complete description of the invention, and how to make and use it. The patent application should include ways to make and use the invention in every conceivable variation in the elements of the invention, including the way the inventor believes is best.

Can a combination of popular technologies be patented?

Yes, if the patent office decides that the combination is not "obvious" (US) or "lacks an inventive step" (non-US) and rejects claims to the combination. This hurdle is almost always raised against patent applications, but can be overcome in debates with the examiner during prosecution of the patent application (patent prosecution refers to dialogues with the examiner to get a patent issued).

Before concluding that something obvious has been patented, examine the claims allowed to issue a patent. The title, abstract and description in the specification may make the claim seem unreasonably broad and obvious. However the actual claims, which define the boundaries of the patent protection, may be very limited and include a non-obvious element or combination.

Unless subject matter is covered in the claims of an issued patent, it is not protected by the patent. Parts of the specification not appearing as claimed elements cannot be enforced.

To overcome an obviousness rejection, an applicant must show that there was no teaching, motivation or suggestion known to those in the technical field ("those of skill in the art") to combine the technologies, and/or that even if there was such teaching, motivation or suggestion to combine the technologies, the combination would not equal all of the elements in the claims of the patent application. For example, just because paints, canvas and brushes were known, the Mona Lisa was not obvious.

Another way to overcome an obviousness rejection is to show the combination constituting the invention yields "surprising and unexpected results". If putting a device A that creates a fog together with device B that produces a pink light results in a blue beam then this is an unexpected result. Paper and adhesives may each be known, but a combination of paper with an adhesive border on one side that is sticky, but readily peels off may not be obvious because an adhesive with such a function was not known in the art.

In hindsight, many inventions may seem "obvious", but the courts have rejected "impermissible hindsight", developed by knowledge of the patent application as support for patent claim rejections. It is easy to think "anyone could have made that combination", but the examiner must use legal criteria to make that call. To find out how a patent escaped or overcame obvious rejections, it is necessary to examine the "prosecution history" (file history) that relates to the debate between the examiner and the applicant to obtain a patent, from the filing of the patent application in a patent office to the patent issuing.

Reviewing the prosecution history may reveal how an obviousness rejection (which is almost always made during patent prosecution) was overcome by an applicant's arguments. Other information obtained from the prosecution history includes the meaning of claim terms (claim interpretation and limitations), which is based on literal meaning in view of explanations in the specification and comments in the prosecution history; and what prior art was considered before the patent issued that was not found by the examiner to destroy

Another way to overcome an obviousness rejection is to show the combination constituting the invention yields "surprising and unexpected results".

novelty or make the invention obvious.

There are procedures (re-examination) for the public to bring prior art to the examiner's attention. Prosecution histories are always reviewed if there is litigation.

Also, the public is able to access the US Patent Office records at portal.uspto.gov/external/portal/pair after a patent application is published (18 months after its priority date) or is issued as a patent. For foreign (PCT) patent applications, the International Search Report listing prior art and the International Patentability Report are published and available to the public about 18 months after the PCT application is filed. Sometimes the US or PCT publications are mistaken for actual patents. The publications provide notice to the public and may be used as prior art against future applications, but these publications do not confer any rights to exclude others from practicing the invention. Although patents and patent application publications look similar, one must check the first page to determine if the document is a patent or merely a published application.

How can there be a series of patents going back in time to a small number of parent (original) patents?

The first application(s) filed on an invention establish a "priority date" for what is disclosed in the application. In the US, a priority date may be established from a provisional (which is not examined but holds that date for one year), utility or design application.

Routinely the examiner might decide there is more than one invention and divide claims into "restriction groups". This forces applicants to elect one group and file "divisional" applications if they want to obtain patents on the other groups of claims.

Applicants may also file continuations of the parent or other co-pending application to prosecute claims not originally filed. To do this, there must be support for the claim elements in the specification of the previous patent application. For example, if the patent examiner has issued a final rejection of the claims in an application, the inventor may want to file a continuation application narrowing the claims by adding additional disclosed elements in combination.

Another way to extend a chain (or "tree") of patents is to file a "continuation-in-part" (CIP) application. This application adds new material to the original specification and usually incorporates the new material into claims. Going back to our pencil example, assume the same person invented the pencil and the pencil/eraser combination discussed above. While the first application for the pencil was pending, the inventor thought of adding an eraser to one end of the pencil. Because the inventor did not include an eraser in his original patent application, he cannot claim an eraser. Therefore, the inventor would file a CIP application with the new disclosure of the eraser and draft claims covering the pencil/eraser combination.

In a CIP, the old material should get the priority date of the originally filed case and the new material should get as priority the date that the CIP was filed. In reality, priority issues are more complex. Also, where in the past priorities usually became an issue only at litigation, recently examiners have been determined to challenge priority dates on the basis of alleged lack of support.

To avoid issuing multiple patents on the same invention by different inventors, the patent office initiates an "interference" (US) or "opposition" (foreign countries), which is a form of litigation. Priority dates and proof of dates of invention are important in this outcome. Only one patent for one claimed invention will survive this procedure.

The further back in time a priority date extends, the more prior art can be cut off because it is not "prior" and the more likely a patentee or applicant is to prevail in a contest where others claim the same invention. However, a disadvantage of creating a patent tree is that patent terms are 20 years from the priority date. So the further back in time the priority date is, the shorter the patent term, i.e. the period during which others may be excluded from making, using or selling the patented product or method.

What does a patent do for the patentee?

Patents do not give patentees the right to practice the invention. Patents give the right to exclude others from making, using, offering for sale, selling or importing the invention as claimed. If those who are excluded make, use, offer for sale or sell the invention as defined in the claims, they infringe the patent and can be sued. A patent is only as useful as the claims that appear at the end of it – and these are sometimes written in cryptic legalese.

How to tell what a patent excludes others from doing

Claims define what an inventor is allowed to prevent others from doing. Claims are identified by a heading including the word "claims" and are numbered sequentially. Depending on what source is used to print a patent, claims will be either at the beginning or end of the patent.

The first part of each claim states whether a composition, an apparatus or a method is claimed. The remainder of the claim lists elements of the invention. No-one may make, use, sell, or offer for sale a product that has all of the elements listed in a patent claim without the permission of the patent owner. If the accused product has each and every element of a patent claim, the claim is said to "read on" the accused product and the product infringes the claim.

Patents do not give patentees the right to practice the invention – they give the right to exclude others from making, using, offering for sale, selling or importing the invention as claimed.

To literally infringe, each claim element must be present in the method, products or apparatus being challenged. There are other forms of infringement, if literal infringement is not found. It is important to see to what the claims relate to because only the same type or category of subject matter can infringe a claim, that is, a light bulb can infringe a claim for a light bulb, but a light bulb cannot generally infringe a method of making a light bulb.

Litigation – offensive and defensive

If a patent is infringed, the owner or exclusive licensee enforces their rights by, for example, warning the infringer and/or seeking a license

Litigation is very expensive, so avoiding it by agreements is preferred...If it can be proven that infringement was "willful", awards of damages may be increased by as much as three times the actual damages.

agreement to obtain royalties from the infringer, and/or suing the infringer. Litigation is very expensive, so avoiding it by agreements is preferred. Remedies include injunctions and monetary damages. If it can be proven that infringement was "willful", awards of damages may be increased by as much as three times the actual damages.

Defenses to infringement include proving the method or product does not have all of the claimed elements in the patent. Also, the patent validity is challenged by determining whether criteria for patentability were satisfied and determining if there was any impropriety on the part of the patentee, e.g. hiding art from the patent examiner.

Are patents a blessing or a curse?

The patent system was instituted based on the belief that the benefits of patents were to reward inventors and stimulate invention. The goal was to discourage trade secrets as a means of protection. Thus, the patent system strikes a balance by granting exclusive rights to inventors for a limited period of time in exchange for the inventor's knowledge and technical expertise. Disclosing intellectual property to the public was to encourage further invention and innovation, using patent disclosures as a building block for further innovations.

Although the US patent system provides protection for inventors for a limited time, competitors are free to design around the invention protected by a patent and "build a better mousetrap" of their own. This energy should benefit an industry. Litigation is expensive, risky and time-consuming, and the need for litigation can be alleviated by licensing and avoiding infringement.

Ultimately, the incentive allowing inventors to reap the rewards from their inventions encourages technological advances that benefit society as a whole, as well as industry and the inventors.

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Lighting industry still learning how to apply advanced LEDs

Some lighting designers view LEDs as a troublesome technology that is only useful for color-changing applications, but the LED community is now moving to address the concerns of the lighting industry. **Tim Whitaker** reports from the Applying Advanced LEDs conference.

"White light is boring – color is the only reason we get excited about LEDs," announced Dominic Meyrick, Lighting Principal of Hoare Lea, a specialist lighting design consultancy, in an impassioned talk at the Applying Advanced LEDs conference, held on 28 June in London, UK. However, there were many other speakers and audience members who could appreciate the benefits of using white LEDs in different applications, while at the same time acknowledging the myriad of challenges still to be faced.

RGB LEDs for architecture: the Sports City Tower, a 1000 ft (300 m) structure being built in the Gulf state of Qatar, will be covered in a state-of-the-art lighting skin composed of around 4000 individually addressable LED elements. The tower will support the Olympic flame for the Asian Games in November 2006. Kevan Shaw Lighting Design is responsible for the tower's lighting scheme, which features a network of RGB LED elements. "Each custom-made unit contains six 1 W LEDs, two of each color, and has custom optics to provide a predominant distribution below the horizontal," said design director Kevan Shaw.

Industry standards

The lack of industry standards is a recurring issue. In a panel session, Kevin Dowling, vice-president strategy and technology at Color Kinetics, listed several organizations that are developing standards, procedures and metrics for the solid-state lighting industry. "There is rapid activity but it's never quick enough," he said. "Standards need to make sense to manufacturers, specifiers and the end users."

The industry has to decide what characteristics to measure, the methods of measurement and also identify accredited laboratories to perform the measurements, said Dowling. Required metrics include luminous flux, efficacy, lifetime, color rendering index (or an updated replacement), light distribution, and binning.

Among the organizations involved in addressing these issues are lighting standards bodies (e.g. IESNA, ANSI, IEC, LTEC), color science and photometry organizations (e.g. CIE, CORM), research organizations (e.g. NIST, NPL, Lighting Research Center) and industry groups (e.g. NEMA, NGLIA). Dowling said that we are "likely to see released review documents this summer".

In late July, the US Department of Energy's solid-state lighting program announced a collaboration with the Illuminating Engineering Society of North America (IESNA) to develop standards for solid-state lighting (for further information see www.ledsmagazine.com/articles/news/3/7/23).

LEDs in building design

Orri Petursson, senior designer with lighting designers Speirs and Majors Associates, said that there are many claims surrounding LEDs and it is hard to distinguish truth from hype. On the majority of the company's current schemes, LED-based products are part of a light source pallet. "In most cases, they take the role of feature lighting, not functional lighting," he said, highlighting three main reasons for this: white light LEDs tend to change color of their own accord and the cost per lumen is too high to be able to compete with conventional light sources. "Also, the quality of white light from LEDs is sub-standard compared with what we are used to and accept." However, for RGB, Petursson agreed with Hoare Lea's Meyrick that LEDs offer a far better system than conventional methods of color mixing.

Most LED products are custom built around a project, rather than off-the-shelf. However, lighting designers want more from their suppliers. "Where's the unique application, where's the unique fitting, where's the blue-sky thinking?" said Meyrick. "We want unique prod-

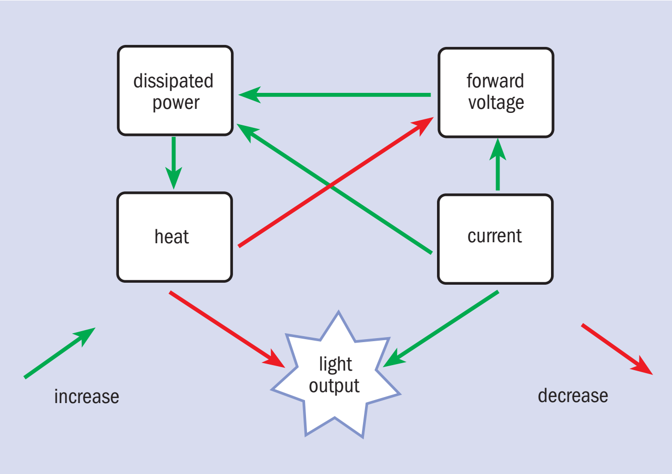

Fig. 1. The usable light pentacle: this complex interaction model shows how changes in different parameters affect the LED light output. Courtesy of Future Lighting Solutions.

ucts from the LED industry – don't ram LEDs into boring fixtures."

"The majority of LED manufacturers get away with not supplying photometric data", said Petursson, and this is against the norm. "For other sources, we wouldn't let the manufacturers through the door without for example seeing the '.ies' files", he said.

Petursson also highlighted the issue of not being able to find replacement LED products when the original LED-based luminaire fails, given the speed of developments. "Will the new product match the other 99 working versions that have been burned in for 20,000 hours?" he said. "Can you ever expect to specify the same product twice?"

Petursson commented on cost benefits and lifetime savings in architectural projects, pointing out that hitting the original budget is the most important factor for his company. "The building budget and maintenance budget come from two totally different pockets," he said.

Quality of white light

After a morning of discussing LED technology, Ken Kane, vice-president product and market development of Lighting Services Inc (LSI) put things into context: "LED developments are important – but not to my customers," he said. "What's important to specifiers and their clients is visual effect – the quality of the light that they're receiving."

During the same session, Color Kinetics' Kevin Dowling said that customers want easier and more flux control, fun and interesting lighting, and the ability to control and enhance moods,environments and ambiance. "In terms of luminaires, lighting designers and architects want more variation, more control and more unique looks, with the ability to paint with layers of light," he explained.

"There is rapid activity but it's never quick enough. Standards need to make sense to manufacturers, specifiers and the end users."

"Luminaires can be used in real applications today", said Kane. LEDs are just one component of the luminaire, "Imagine if we had to go to a store and buy a filament, a bulb enclosure and a screw-in socket, then put them all together to make an incandescent lamp," he said.

For LSI, which has licensed TIR's Lexel technology for use in its LumeLEX luminaire, the focus is on interior lighting and the key factors are high quality, directional light, as well as accuracy and consistency. The ability to easily adjust color temperature is a key feature of LSI's luminaire. Kane told *LEDs Magazine* about a meeting with museum and gallery curators, who could choose the best color temperature (around 4000 K) to display their artifacts, while staying within the maximum illuminance level of about 50 lx mandated by conservation requirements. "The problem was that at such low light levels, the halogen system that the LumeLEX was being compared with looked muddy, and did not render the colors as well," said Kane.

UV content is also very important for museum and gallery lighting, and is one aspect of photometric information that should be supplied, ideally in the same format as for a traditional source. Crucially, this information has to be at the system level. "Users don't care what the light output and distribution of a CFL is like, until it's inside the luminaire," said Kane. "The same applies to LEDs."

LEDs in architecture: positives and negatives

Another conference in London in June also discussed architectural lighting. One of the highlights of the Future of LEDs event was a talk by Rogier van der Heide of ARUP, who won the 2005 IALD Radiance award for his lighting design work on the Galleria shopping mall in Seoul, Korea (see www.ledsmagazine.com/articles/features/2/1/4). The Galleria exterior, arguably the world's largest TV imaging system at ultra-low resolution, has become an attraction in its own right, as well as pulling in many more shoppers.

"Lighting provides a meaningful addition to the built environment," said Van der Heide, suggesting that lighting decisions should be driven at a strategic level rather than being an afterthought. "We are interested in the value that we can add as designers."

Lars Bylund, a professor at the Bergen School of Architecture in Norway, highlighted a number of barriers for LEDs. These include a lack of definitions and standards, as well as numerous performance, price and technical issues. "For a project that will be built in two years' time, we are required to plan and specify the lighting now," said Bylund. "This makes it very difficult for us to use LEDs."

Bylund also questioned the use of existing infrastructure. "Should we build LED installations in the same way as we build with fluorescents?" he asked. Another problem is the use of colored LEDs for city beautification projects, which can add to overall light pollution levels and risks making some cities looking like miniature versions of Las Vegas, said Bylund.

But there are many positives relating to energy savings and maintenance. Bylund was involved in the project to install LEDs into the Turning Torso building in Malmö, Sweden (see www.ledsmagazine.com/articles/features/3/4/4). White LEDs were built to match the interior curved surfaces and reduced the load by 60% compared with fluorescents, while removing maintenance concerns.

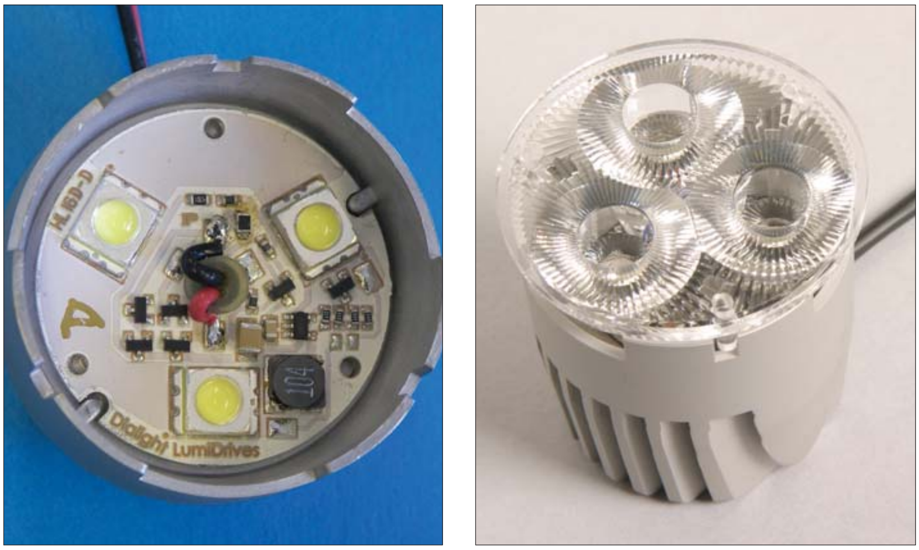

Fig. 2. Dialight-Lumidrives has built modules with on-board drivers for low-voltage applications that eliminate electrolytic capacitors and incorporate thermal feedback.

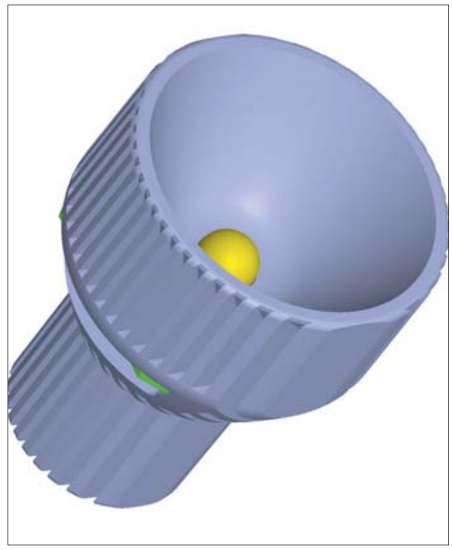

Fig. 3. Integrating optics: a precision casting allows a combined heat sink and reflector.

Kane spoke about lifetime, acknowledging that the rules for traditional lighting don't readily apply to LEDs. Even so, customers should expect a system warranty from a luminaire manufacturer; Kane gave the following warning: "If you don't see system output data – run!"

LED success factors

Volker Mertens, head of LED marketing for Osram Opto Semiconductors, discussed some of the success factors associated with using LEDs. To achieve a similar lighting function as for other light sources, he said, the cost of LED systems is often a disadvantage. Of course, customers are concerned about the overall system cost, including optics, drivers and heat sinks, as well as the LEDs. High costs can be offset in part by the development of standard LED products at the module and subsystem level, and this is what the new Osram LED systems division hopes to achieve.

Other advantages include fully exploiting the technical benefits of LEDs, for example in color-changing or to simulate human biorhythms. "Retrofits with standard sockets can get LEDs faster to market," said Mertens, "but this is not a good long-term solution due to heat management issues."

Francois Mirand, European technical manager for Future Lighting Solutions, admitted that comparing different LEDs can be a problem. However, it is possible if the key performance factors are understood and the usable light is determined for each application (see figure 1). Key factors include the luminous flux, which is usually specified at a junction temperature of 25 ºC and a typical drive current; the packaging thermal resistance; the extent to which the flux and forward voltage vary with temperature; and the effect of changing the drive current up to its maximum level. Not only is the maximum LED junction temperature important, but also the operating conditions at which the stated lumen maintenance can be achieved.

"LED developments are important – but not to my customers. What's important to specifiers and their clients is visual effect – the quality of light that they're getting."

Drivers and optics

Gordon Routledge, managing director of Dialight-Lumidrives, discussed LED technology trends such as moves to higher drive currents up to 1500 mA and higher maximum junction temperatures of up to 185 ºC. While this can make some applications much easier, notably automotive lighting, Routledge says that clients are also becoming much more demanding, which presents even more challenges.

Built-in drivers (i.e. drivers incorporated within the LED fixture) represent an opportunity to reduce system costs and increase system efficiency while adding more features, but this could happen at the expense of increased form factors and thermal challenges. Often, electrolytic capacitors determine the life of the driver.

Lumidrives has built modules with on-board drivers for low-voltage (12–24 V AC or DC input) applications, which eliminate electrolytic capacitors and have on-board thermal feedback (see figure 2). These operate at 350 mA, and 700 and 1000 mA versions with the same form factor are planned for later in 2006. Mains voltage is more problematic, partly due to the need to ensure EMC compliance.

Tomi Kuntze, managing director of Ledil Oy, said that the challenge of integrating optics in LED-based luminaires is to serve money through integration without endangering the quality and differentiation of end products. Optics save a number of useful purposes, such as redirecting and reshaping light output and smoothing color variations, all of which help to cut down the system price of the finished luminaire.

The first step is to integrate the optics with the LEDs, using mechanical methods, glue, heat or adhesive tape. Next, it is possible to integrate mechanical and heat transfer elements, which could involve the use of interchangeable elements (lenses or optics), or building optics with multiple elements, or combining a heat sink and a reflector as a single part (see figure 3). The next step is to consider ways to integrate decorative and protective elements and finally to incorporate control electronics into the finished luminaire. ●

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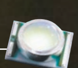

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Photonic quasicrystals boost LED emission characteristics

Custom photonic quasicrystal structures can help to efficiently extract light from LEDs and place it into a desired emission profile, according to **Majd Zoorob** and **Gregory Flinn**.

The case for high-brightness LED adoption lies increasingly with the potential cost savings made possible by reduced servicing, longer lifetimes and higher overall efficiency, as well as better technical functionality for many lighting applications. These cost benefits for the end-user are at present balanced by considerable performance challenges still facing the manufacturing industry, including providing sufficient luminous flux for projection applications. To help achieve these goals, the use of photonic quasicrystal structures can both significantly enhance the luminous flux emitted by current LED technology and also place the light where it is needed.

Improved light output

High-brightness LEDs represent a multi-billion dollar market that is predicted to grow to $8.2 billion by 2010. Strong future growth is anticipated, in particular for ultra-high-brightness devices. In moving from niche applications to true mass adoption, potential illumination markets include room and desk lighting, projection lighting for the automotive and display markets, and task lighting. Also, development of existing flat screen backlighting applications is expected to evolve beyond the demand associated with mobile phone handset displays.

Nonetheless, before all these lighting applications can be addressed adequately, the industry still faces considerable performance-related challenges. Supplementary to color matching and color balance issues over the lifetime of a device, the total and specific luminous flux currently available is still only borderline for some tasks, despite the increased efficacy achieved by modern LEDs. White light projection tasks such as automotive headlighting and projection displays are two examples of applications needing exceptionally highly efficient, as well as tailored, light output.

To help meet these demands, the effective light output of an LED can be optimized by both improving photon extraction efficiency and effectively shaping the intensity distribution for the task at hand, uniform or not. Planar photonic crystals, and in particular photonic quasicrystals, are a cost-effective and flexible way of achieving this goal.

Photonic crystals in optics

The term photonic crystal (PC) simply refers to a repeating structure in an optical medium, the characteristic dimensions of the structure being comparable to optical wavelengths (hence "photonic"). These structures can be 1D, usually as repeating layers of differing materials; 2D, as will be discussed here; or even 3D, these structures being the most difficult to prepare and being the focus of much research. The term "crystal" refers to the repeating structure in one, two, or all three dimensions, in direct analogy with the structure of true crystals found in nature. Similarly, this repetition is also critical to their function.

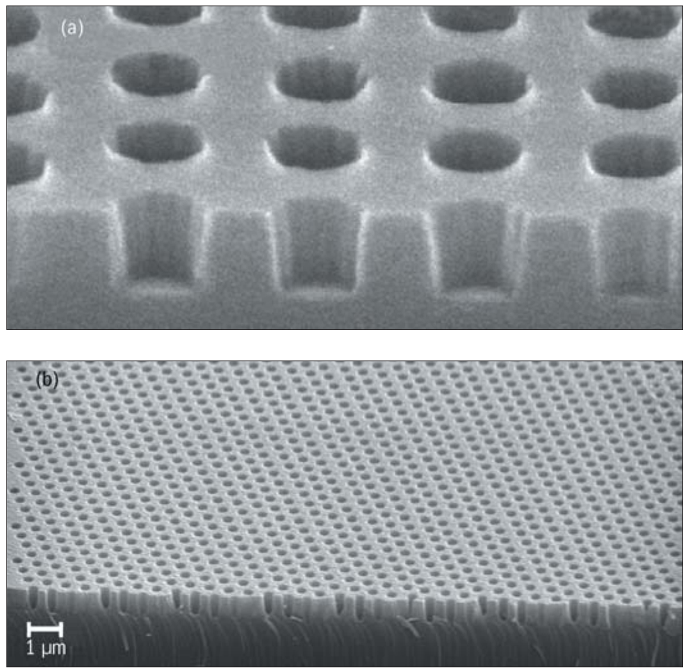

Fig. 1. Planar photonic crystals etched into a dielectric surface. Modern nanoimprint lithography enables both high accuracy of features of the array (a), as well as high repeatability (b). Courtesy of Molecular Imprints Inc.

Instances of indirect application of PCs have been present in optics for many years, a well documented but somewhat simplistic example being the Bragg reflectors used in semiconductor vertical-cavity surface-emitting lasers or in some LED structures.

Planar PCs, i.e. those credited with the more comprehensive photon management qualities often highlighted in the photonics press, can be generated by etching 2D arrays of shaped structures into a dielectric surface (see figure 1). Although by no means confined to the optical regime, when fabricated with appropriate dimensions these arrays form the optical analogy of a semiconductor material, producing a range of allowed or disallowed photon states of the PC lattice. Just as for a charge carrier moving through a semiconductor, the continued propagation of photons incident on the PC is subject to the properties of the lattice in relation to the direction of travel.

Suitable choice of symmetry for the array, pitch (generally submicron, $\lambda/2$ to 2λ), depth (100–200 nm) and shape of the etched

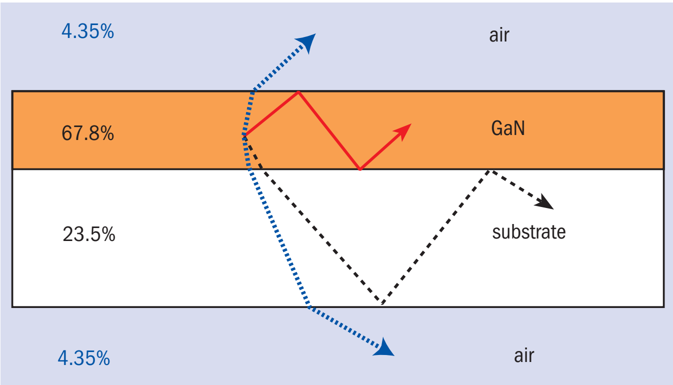

Fig. 2. Light emission from the active layer in an LED is hindered by the high refractive index step between the semiconductor layer and air. Figures show the percentage of light in each layer.

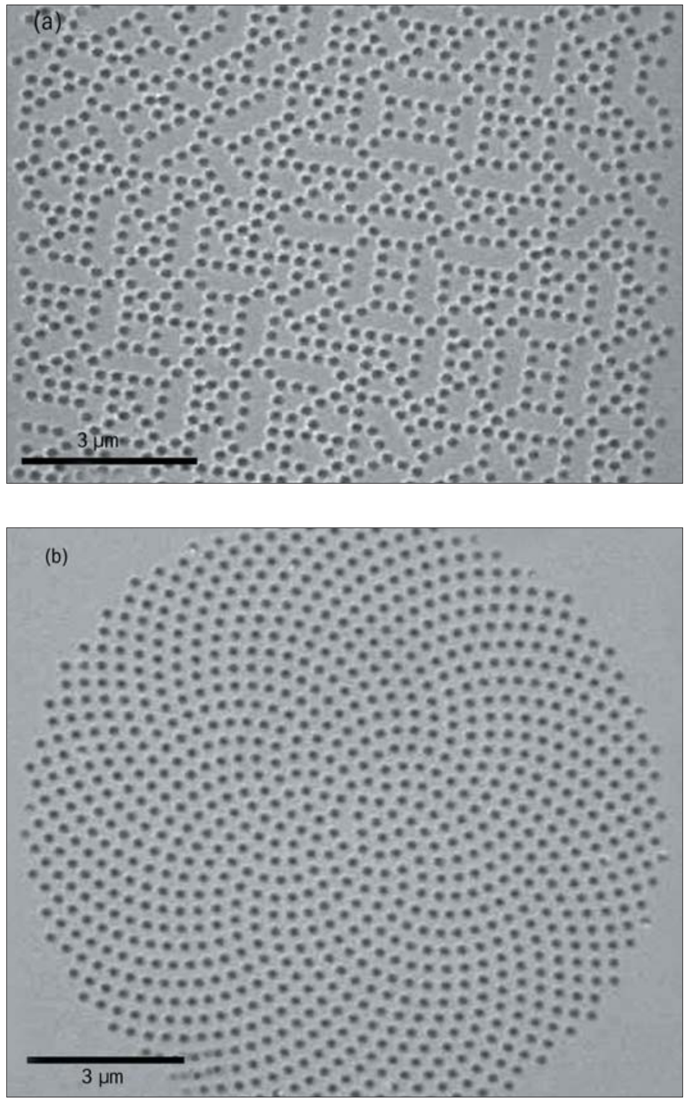

Fig. 3. SEM images of fabricated pinwheel (a) and sunflower (b) photonic quasicrystals.

features are all factors that influence the specific optical properties of the structure. Further fine-tuning can be accomplished by filling the structure with a material of differing refractive index.

In simple terms, planar PCs represent a range of tools that can be used to control the emission and propagation of light on a scale small enough to permit their use in integrated optical systems. More specifically, this includes short-range spatial beam steering, spectral filtering, polarization control, optical time delay and beam division. For example, a planar PC structure introduced into the output facet of a VCSEL provides increased lateral control of the lasing mode profile, enabling these top-emitting laser diodes to be driven at higher output powers without sacrificing the coupling efficiency into single-mode telecommunications fibers (see, for example, www.alight.dk).

LED manufacturing

The increased interest in the use of planar PC structures for more complex optical tasks is due to the recently acquired ability to create intricate 2D structures using nanoimprint lithographic techniques. In the instance of LED manufacturing, the PC is imprinted into the topmost surface of the LED, namely into the semiconductor material covering the active layer.

Critically, nanoimprinting lends itself to the cost-effective manufacture of custom photonic crystal patterns in large volume and is thus an important enabler for the LED industry. As we shall see, it is the ability to reliably produce structures with seemingly peculiar symmetries that allows the realization of LED devices with both enhanced light output and tailored illumination profiles.

Emission enhancement with photonic crystals

The problem with LEDs is the high refractive index of the semiconductor material sandwiching the active quantum well layers. As the semiconductor interfaces directly to air at the output facet, a significant amount of the light generated inside the active region remains trapped within the capping layer (see figure 2).

Extraction efficiency can be improved by something as simple as roughening the emitting surface, or by adding features like microlenses to the surface of the LED to help channel the emission. However, early PC-patterned LED structures have already been shown to increase the light extraction efficiency several-fold and now newer, optimized designs are responsible for generating still higher extraction efficiencies. The PC structure improves emission extraction by providing preferred leakage paths out of the LED structure for photons trapped in the capping layer.

Emission management with photonic quasicrystals

In spite of the gain in extraction efficiency, the problem with regular PC structures is that they are anisotropic, i.e. the regularity of the structure translates into a gain in the light extraction that is directionally dependent. More exactly, there is an interplay between the gain in overall extraction efficiency, its variation into different emission directions and the overall illumination homogeneity of the emission cone. This interplay is decided by the design parameters chosen for the PC, with the result that not all of these aspects can be optimized independently of one another. For example, while the overall intensity can increase compared with a Lambertian emitter, this can be at the expense of the spatial distribution of the light flux.

The most common PC geometries are based on naturally occurring symmetries, like square or triangular, but similar structures can be

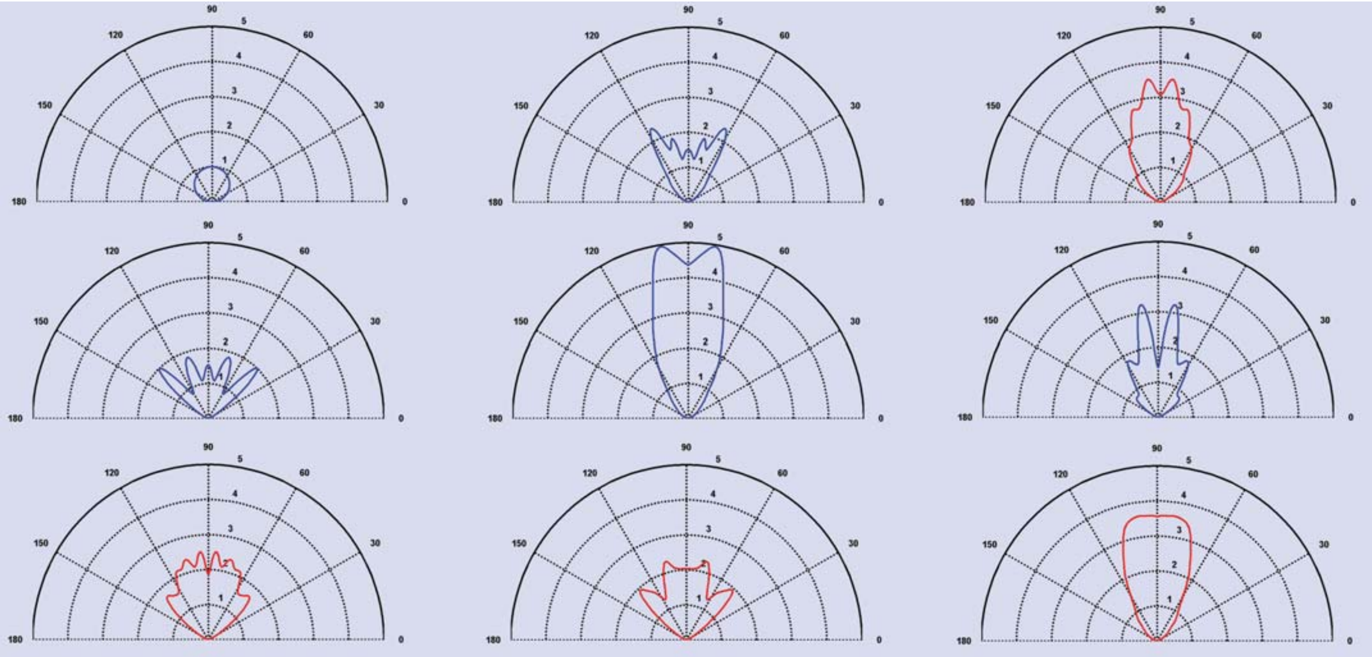

Fig. 4. Comparison of simulated PC and PQC LED far-field emission patterns for different lattice parameter combinations, normalized to a Lambertian source (top left). The profiles illustrate the optical power emitted into different angles: emission profiles generated by PQC structures show better illumination homogeneity.

Table 1. Enhanced performance with PQC structures

	Standard LED die	Roughened LED die	LED die with optimized regular photonic crystal	LED die with photonic quasicrystal (predicted)
LED die: light in 30° cone	7.65	12.4	34	>37.5
LED die: total line output	11	22	35.2	~38.5
LED die: percentage light in 30° cone	69%	56.6%	<97.7%	98%
LED die: far-field emission uniformity	50%	50%	18%	>60%
Packaged LED: extraction efficiency enhancement in 30° cone	1	1.62	4.4	>4.9

Comparison of emission characteristics for a variety of LED emission surfaces. Best overall performance comes from PQC structures, providing significantly better light extraction and directional control.

made with unusually high levels of symmetry. Structures exhibiting "artificial" symmetries are termed photonic quasicrystals (PQCs) and seem to lack order when examined over a short range (see figure 3).

The advantages of PQCs over regular PC structures lie in the broader design space available to the optical engineer. That is, PQCs can be designed to perform similarly to regular PC structures, but at the same time allow more flexibility, greater design tolerance and less directional dependence. The reason is that although the overall optical properties of any PC are by and large determined by its long range repetition, the lack of short range order exhibited by a PQC acts to blur the dependencies of these properties.

Although figure 4 shows only a limited number of PC and PQC parameter combinations, it is illustrative of a general effect seen with PQC structures, namely that the far-field emission pattern is flatter. An additional result is that the profile is rotational symmetric, a property that is not the case for lower order PC structures.

For many illumination applications the emission in far-field is ideally flat. Projection display applications are a good example of where costly optical design is necessary to remove variations in the projected intensity from conventional illumination technologies.

Conversely, international automotive headlight standards call for a wide field of illumination containing specific intensity maxima and minima, as well as the sharpness of the cut-off (for further information see en.wikipedia.org/wiki/Headlight). In this instance, a tailored quasicrystal structure may be preferable, as both the light extraction and illumination placement can be optimized to a higher degree than is possible with regular PCs.

Working the numbers

Table 1 compares light extraction efficiencies for four different types of top-emitting LEDs; a simple flat surface, a roughened device and dies with PC and PQC structures. Values are given both for the total emission and for emission into a ±30º cone (a value of ±24º is a common criteria for digital light projection applications).

While the values given for flat and roughened LED surfaces are based on calculations given in reports in the literature, for both PC and

PQC LEDs the values given represent simulations using optimized parameters for typical flip-chip GaN structures. In the case of a regular PC, this means choosing parameters that maximize the emission intensity into the designated cone.

Both the PC and the PQC structures improve total emission and the amount of light channeled into the ±30º cone. The PC structure shows considerable intensity variation in the illumination profile – parameters could be re-optimized to improve the profile, but this would be at the expense of extraction efficiency. On the other hand, the PQC structure actually improves illumination homogeneity and overall emission simultaneously, pushing almost five times more light into a 30 ° cone. In terms of brightness close to the central axis, luminous flux is increased by a factor of 10 compared with an unroughened LED. For the improvement in total light extraction, an un-roughened LED die that is encapsulated can extract 20.9% of the total light from the top surface, while an encapsulated PQC LED would extract 47.4%.

The future for PQC LEDs

The need to efficiently extract the light generated inside the active layer of an LED out into a desired illumination profile is a major hurdle facing LED development. The beauty of the PQC approach, in addition to the aspects already highlighted and contrary to some other surface treatments, is that the enhancement can be easily applied to the total emitting area, even for larger LED devices. The enhanced luminous flux thus scales linearly with increasing LED mesa size.

Design-specific aspects, like custom illumination profiles and fabrication tolerant designs, can also be readily included. Integration of the nanoimprinting step into the production process thus allows manufacturers to maximize LED functionality for a range of lighting tasks while minimizing supplementary manufacturing costs. Moreover, the need for complex beam-shaping optics in the packaging is reduced, thus simplifying overall LED design and improving cost-effectiveness still further. Significant work has already been undertaken with leaders in the LED industry to closely examine these aspects.

Notably, the simulations highlighted in the text only account for the enhancement to the light extraction from the LED surface, all without invoking the Purcell effect. That is, additional benefits are expected when the PC or PQC lies close enough to the active region to be able to influence intrinsic emission directly. Although work is in progress with the industry to develop optimized LED die templates, initial simulations for devices indicate that wall-plug efficiency for LEDs could top 75%. Should this development come about, the prospects for conventional lighting technology should dim considerably in comparison with the bright future anticipated for solid-state devices.

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LEDs MAGAZINE

Optical design software improves LED system design and validation

Optical design software can shorten and optimize the design process for systems that include LEDs or OLEDs, as **Jean-Baptiste Haumonté** of Optis describes.

Simulation software can significantly improve the design process of LED- and OLED-based systems, and virtual validation without physical prototyping allows engineers to save time and money.

The first step is to evaluate the capabilities of the software that will be used for the design. A good lighting design including LEDs requires very accurate simulation and analysis tools. Thus optical design, photometry, colorimetry and photo-realism capabilities are necessary in the design process of LED-based systems.

For instance, photometry allows designers to simulate and analyze the intensity, illuminance and luminance of the 3D system. The more accurately these physical results can be simulated, the better optimized the final LED-based system will be. Moreover, very accurate algorithms (full spectral propagation) based on real physical laws are a necessary condition for improving the design process. These reasons explain why very advanced software in optics is the necessary first step in dramatically improving the design process.

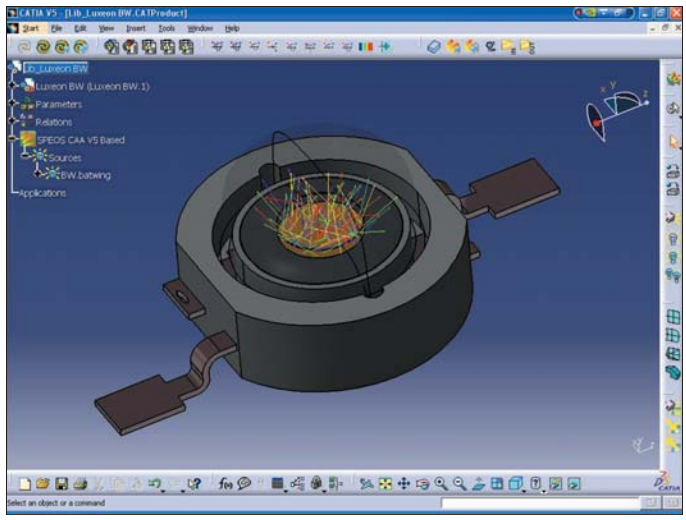

Fig. 1. The Luxeon Batwing LED is one example from the library of the SPEOS CAA V5 Based software from Optis.

Device catalog

The second step is the LED or OLED catalog availability within the software. Ideally, a designer using LEDs to build a lighting system needs to find the best component to optimize and to get the best lighting result. To make this possible, optical design and lighting software has to provide the largest-possible LED catalog to develop lighting industrial systems. In other words, with such a library integrated in the software, the designer can very easily choose a component from a long list, and is able to try several LED configurations.

Overall, two points are extremely significant in this library. Firstly, all the LEDs in the catalog must be commercially available and the library must include components from all the major LED manufacturers (see figure 1). Moreover all the components in the catalog have to be accurately referenced. Thus, industrial reality is imported in the software and gives much added value by hugely increasing the realism and the relevance of the simulation.

Secondly, the way in which the LED is modeled is also fundamental in order to obtain very good results that can be virtually validated and thus exert a real influence on the design process. The best way to do that is to first model the mechanical geometry of the component and then to measure its light-emitting properties with a very accurate optical bench. Only after that does it become possible to obtain a realistic model based on a market-available LED that can be used in the simulation.

Design validation

To increase accuracy, geometric modeling is important because light can interact with the LED structure as well, influencing the propagation. This explains why ray files are not sufficient for obtaining high-level results. Exactly the same method is used for OLED modeling; OLED libraries can be made as easily as LED libraries. Optis supplies software with algorithms based on accurate physical laws and with libraries made up of measured LEDs. These online catalogs are widely used for a range of different applications such as displays, light guides for cellphones, headlamps, tail-lamps, yacht interior design, architecture and many more.

Algorithms and catalogs are two necessary factors for improving the process of LED-based systems design. When these two elements are present it is possible to save time and cost, to improve system performance and to optimize quality.

One of the goals of software is to virtually validate a design to reduce the number of physical prototypes. This requires a very high level of realism in the software and significant gains can be achieved when this is realized. Algorithms and libraries are necessary but not sufficient.

The third important factor is the analysis capability of the software. The aim is to fully understand the results obtained with a mechanical design using LEDs from a catalog, enabling adjustment of parameters such as position, power and color of the LED. This adjustment will in turn reduce ghost images, stray light and reflections in the system that could negatively affect the performance of the design.

Automotive headlamps

Headlamps offer a good example to illustrate the advantages of a device library for virtually selecting the appropriate LED. Automotive lamps

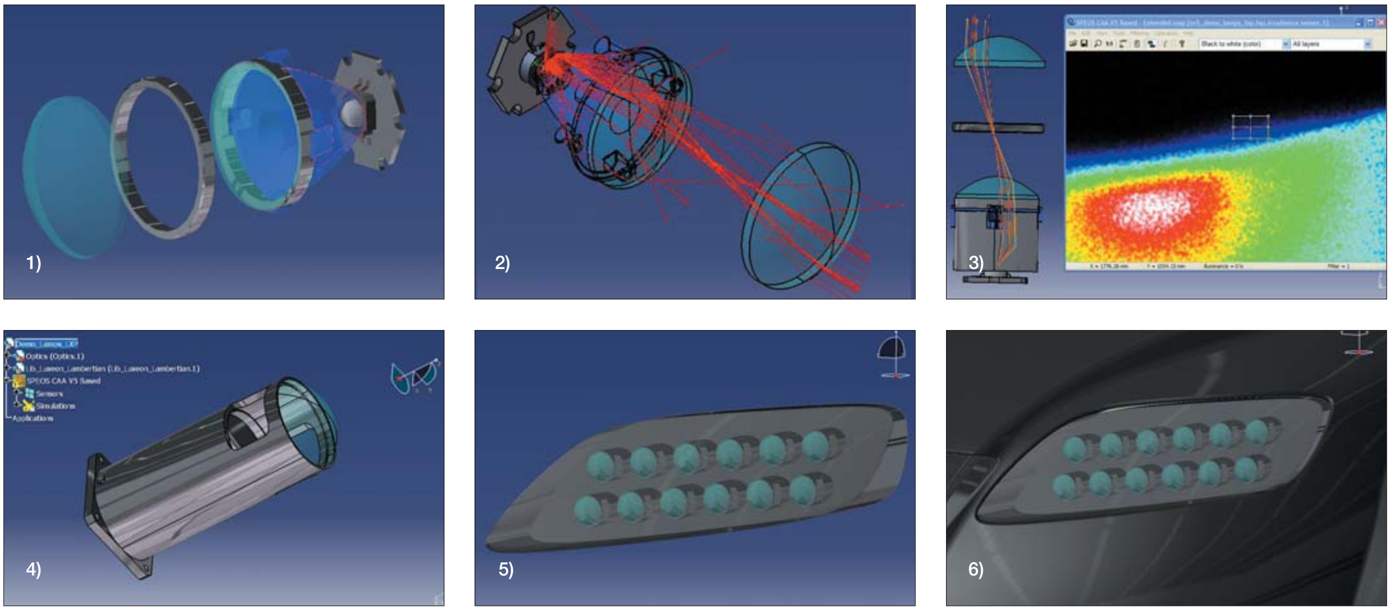

Fig. 2. Process for LED headlamp design using the SPEOS CAA V5 Based software: (1) LED opto-mechanical design; (2) 3D ray tracing; (3) photometric analysis' (4) LED ready to be inserted into the headlamp; (5) complete LED headlamp; (6) LED headlamp in the concept car.

such as low beam and high beam forward lighting, turn indicators and fog-lamps involve different colors of light, and can be designed to include LEDs. The first step in the design process is the mechanical design and the second step is the optical design including reflectors for example. Then (O)LEDs are added from the library – power, wavelength (color) and the LED manufacturer can all be selected. Figure 2 shows the process used for the LED headlamp design, while figure 3 show the Audi Le Mans concept car with LED headlamps.

Next, the simulation can be launched, in which the user runs the photometry and photo-realism software tools to see the lit appearance of the lamps. Then analysis starts and can include, for instance, lamp colorimetry. Several tools can be used to improve this process: multi-configuration simulations can be applied (a series of LEDs rather than trying one by one); optimization of the position/orientation can be performed thanks to a powerful optimizer engine; and tolerances can be automatically studied to find the acceptable limits before production of the full system or to see how it will behave in extreme cases. As a result, the process is drastically shortened and the headlamp is highly realistic. The virtual prototype can be validated without having to spend lots of money building an actual system using real LEDs.

Avoiding hot spots

The luminous keypad of a cellphone can be taken as an example to illustrate the reduction of stray light and hot spots (light concentration) in a system. The keypad of a cellphone contains a light guide that is designed to illuminate all the buttons as uniformly as possible. LEDs are commonly used as the light source for this kind of application. Light coming from the LEDs propagates into the guide, but the shapes and features within the light pipe have to be modified in order to avoid hot spots in certain parts of the keypad (see figures 4 and 5).

Three tools are very useful to overcome hot spots. First, optimization can automatically help to find the best shape or LED position/orientation to get a very efficient result. This can be powered by a genetic optimization engine for instance. Parameters and variables are defined by the user, and the software will then find the best solution. This drastically reduces the time it takes to design the guide – moreover the result will be excellent.

The second tool is the multi-configuration box to automatically test several LEDs, positions and colors etc. This allows the designer to perform unlimited "what-if" scenarios and to choose the best result from a whole range of possibilities.

Finally, some software packages have specific tools for the in-depth analysis of ray propagation. One example is SPEOS from Optis, which incorporates LXP (Light Expert). This module is dedicated to tracking the stray light and hot spots within a system. It is possible to link an area of a photometric map to the ray propagation in the mechanical system. Users can also select surfaces of the system to see which rays contribute to the propagation. This allows users to understand very accurately how a LED source propagates within a cellphone and why it generates problems such as stray light and hot spots. Again, performance and time savings brought about by in-depth analytical capabilities will help to improve the process.

Standards

To complete the analysis of these LED systems, the fourth step can be the compliance with international standards and regulations. In several applications standards have to be applied before launching a product on the market. In particular, this is the case for automotive headlamps. Today software can virtually check that European (ECE) and American (SAE) standards are being met for the lighting or colorimetry. Physical tests are not required to be sure that the system is marketable.

Conclusions

Software is very important in LED- and OLED-based system design. The benefits include huge savings in engineering time, improved product quality and performance, virtual validation and reduction of the number of physical prototypes that generate impressive cost savings. In a competitive world, significantly decreasing the time to market

Fig. 3. Audi Le Mans concept car with LED headlamps designed by Ruetz, a German engineering company, using Optis software (see www.sae.org/automag/techbriefs/ 07-2004/1-112-7-52.pdf).

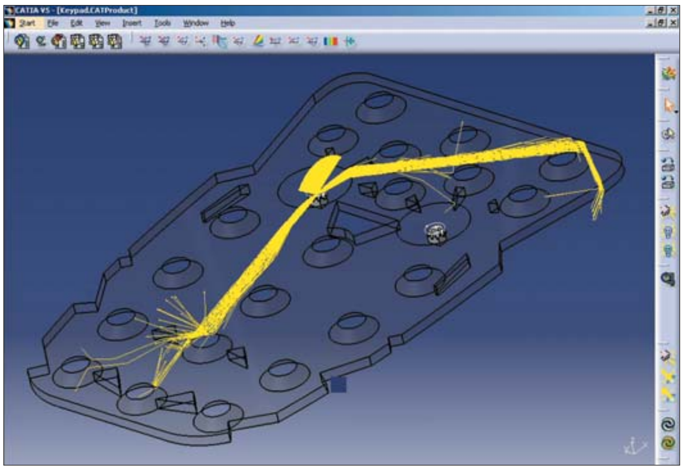

Fig. 4. Modeling and simulation of an LED-based light guide helps to avoid hot spots in the keypad of a cellphone.

Fig. 5. Lit appearance of a cellphone keypad.

can be decisive. Cost reductions allow increased profitability and quality reinforces the competitive advantage of a company. All this is possible by improving the way LED-based products are designed, by using the latest generation of lighting design software. ●

About the author

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VEHICLES

Optical and thermal designs hold key to Schefenacker's LED headlamp development

Schefenacker is using sophisticated optical and thermal approaches, as well as an in-house LED manufacturing capability, to develop automotive forward lighting using LEDs.

COMPANY PROFILE

OSRAM Opto Semiconductors – LEDs combine impressive economy and luminous intensity

For a long time the use of LEDs was restricted to indicator lights on electrical equipment, effect lighting and a few experimental light fittings for the home. Now, however, these tiny light sources are being used more and more in general lighting applications.

AIRCRAFT

LED modules offer a bright future for aviation lighting

LED lighting offers exciting benefits for aircraft, both in terms of how the lighting can be designed and the installed functionality it can deliver.

INDUSTRIAL

Motion capture cameras surrounded by LEDs

Motion capture systems, with applications in life sciences, entertainment and engineering, use cameras with integrated LED light sources.

LEDs MAGAZINE

Full-color video LED billboards feel the impact of alternative technologies

Smaller LED display manufacturers could struggle in the face of decreasing prices and the emergence of competing technologies such as digital ink, according to **Peter Pihos** of EDG Research and Consulting.

It is hard to imagine that only five or so years ago, when the large-area video display industry was transitioning completely to LED-based technology, that anything in the near future would affect the direction or potential that almost all were expecting.

The outdoor market has been having great success, with the sale price of displays dropping annually, allowing for much larger displays to be built along with many new interesting applications. The indoor market seemed to be growing well, servicing applications that needed higher resolution. LED technology produced displays with outstanding picture quality, albeit at very high pricing, serving niche markets where other technologies such as projection had difficulties, particularly with ambient light issues.

So life and business was good, LED was king, and display manufacturers and component companies anticipated a long run without much interference. The LED video industry has enjoyed a 7–10% annual sales growth rate despite continuing price reductions, and the production of LED displays measured in square meters has grown at a rate of approximately 25–30% annually. Most people believed that it was unlikely for anything to strongly influence this trend.

In fact, EDG Research and Consulting started to see a possible anomaly to this trend four years ago when we were researching LED video displays used in advertising networks. We interviewed the top digital display networks, ad agencies and national advertisers to gain an understanding of what was involved. They shared with us both their optimism and concerns about the viability of the media.

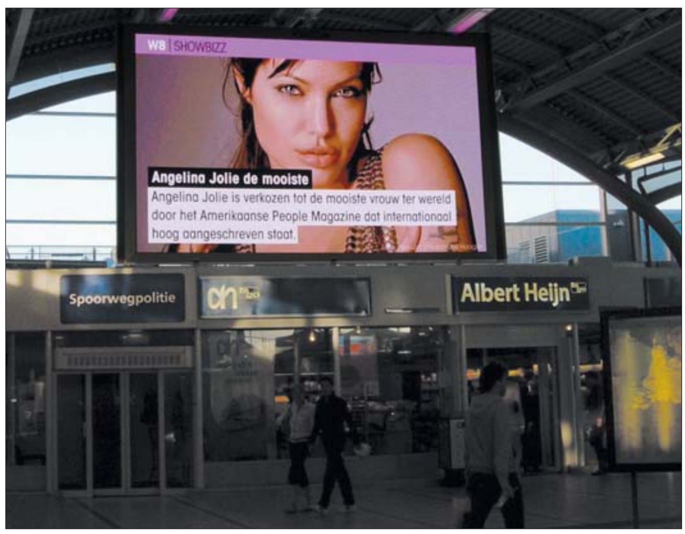
Still images not video

EDG discovered that a large majority of advertising systems were not showing video images. Some had minimal animation, but most were predominately showing simple, full-color images.

There were several reasons for the absence of video, such as regulatory issues surrounding moving images near motorways. Also, it seemed that clients did not want to go to the expense of creating a custom-made video advert without supporting audio that could not be used elsewhere.

It occurred to EDG that the practical usage of the displays in this environment did not take advantage of the main performance feature of LED video systems; that is to say, if you were not showing video on the display then why should one want to purchase a technology that incorporates video capability as a selling feature?

Clear Channel has unveiled a network of LED billboards in Las Vegas, comprising six 14 × 48 foot displays from Yesco Electronics that each contain 449,280 LEDs with a pitch of 20 mm (see www.ledsmagazine.com/articles/news/3/5/9). However, the company is also using Magink technology – see "Clear Channel works with Magink and LEDs" box.



Viacom, one of the world's leading entertainment content companies, is building a digital signage network at railway stations in the Netherlands using LED displays supplied by Lighthouse Technologies. A P10 10 mm LED video screen measuring 6.4 m wide × 3.84 m high has been installed on the main concourse of Utrecht Central Station, the country's busiest railway station. Viacom believes that advertisers are more interested in, and will get more return from, this type of captive audience medium. The fully developed system will consist of LED screens in the network of station's central halls, along with LCD screens on the platforms (more details at www.ledsmagazine.com/articles/news/3/8/5).

Clear Channel works with Magink digital ink technology...and LEDs

Clear Channel Outdoor, the world's largest outdoor advertising company, is using both LEDs and digital ink technology in different electronic billboard networks in the USA and the UK. The company's networks in Cleveland and Las Vegas (see www.ledsmagazine.com/articles/news/3/5/9), as well as a third rolled out in Albuquerque in August 2006, use LED displays. Meanwhile in London, Clear Channel is currently building a series of 5.3 × 2.5 m full-color digital ink billboards that are supplied by Magink Display Technologies.

The Magink billboards use reflected light (sunlight in daytime and front lighting at night) to display the image, so that bright and/or direct sunlight increases rather than reduces the visibility of the screen. The Magink digital ink technology is based on patented organic materials. The ink molecules are arranged in the shape of a spring or spiral helix, and their density and angle is manipulated by electricity to create all colors of the visible spectrum, including all gray levels. For the billboard application, the digital ink is located between glass.

JCDecaux, a leading outdoor advertising company, premiered a network of Magink digital ink billboards in Cannes, France, to coincide with the city's film festival in May.

Clear Channel Outdoor's first London billboard to feature digital Magink technology.

Magink's Ruth Poliakine says that the billboard displays have an effective resolution of 9 mm pixel pitch, and the technology can present full motion capabilities with a typical refresh rate of 50 frames per second. Overall power consumption is low, although front lighting is required at night because the display is not self-emissive. "Once displayed, an image is sustained for an unlimited period of time without requiring additional power," says Poliakine, adding that because the inks reflect visible light and are protected from UV light, a long display life can be expected.

The billboards being installed at 10 London sites are networked from a central hub and will carry multiple adverts from five advertisers and one news/traffic content provider, in the form of repeated, high-impact static images, rather than video, for regulatory reasons.

So why is Clear Channel working with both digital ink technology and LEDs? Michael Scott, technology director of Clear Channel Outdoor in London says that the company is rolling out digital displays in various environments and will be choosing the most appropriate technology for each. "LED is currently the only technology available for the size of displays in the US," he says, "whereas the Magink product is a more cost effective option for the size of displays in London and the requirement for static, rather than video, images."

- Clear Channel Outdoor: www.clearchanneloutdoor.com
- Magink: www.magink.com

This presents a dilemma of sorts. For advertising billboards – the market application that many feel has the potential for significant growth – it may be that video is not needed. If this is largely true, then it could leave the door open for another technology to impinge on the market by offering different performance benefits.

Alternative technologies

This is indeed what has happened. Recently, two major outdoor advertising companies, JC Decaux and Clear Channel, have announced major commitments to the Magink technology for their outdoor billboard programs. Magink is based on full-color digital ink, and the technology manipulates the ink molecules to generate all colors of the visible color spectrum, including all gray levels. If others are to follow this direction it could appreciably affect the growth of the LED video industry.

The other factor that will affect the LED video industry is the emergence of LCD technology into the large-area segment of the market. LCD technology is now capable of producing displays in the 40 to 100 inch diagonal range, moving into what had been the domain of high-resolution LED displays. And LCDs are doing this at a price that is extremely low in comparison to the highest-resolution LED displays.

Experts that follow LCD technology anticipate that the trend for bigger displays and lower prices will continue. How low will the pricing go? The *Wall Street Journal* recently stated that the price of LCD panels dropped 18% in the first quarter of 2006 alone.

This is an industry that continues to heat up, with massive investments in new manufacturing facilities. The manufacturing cost for LG Philips LCD panels was quoted as approximately $1795/m^2, but unfortunately for them the market price was only $1575/m^2.

The effect on the LED industry

You may be asking what this has to do with LED components. Firstly, if alternative technologies such as Magink are adopted in the outdoor billboard market, this will limit the number of LED displays that are required.

A second issue is that the LED video industry is faced with a continual decline in the pricing of finished products. The pricing is being driven by a new generation of display manufacturers located in China and elsewhere in Asia that are producing some very impressive technology at a cost which can be almost half the pricing one would find in popular manufacturing locations in Eastern Europe. To balance this trend, if the industry is to maintain the level of dollar-value sales growth that it has enjoyed in the past eight years, it would require a disproportionate increase in the number of square meters sold.

It is possible that the loss of display sales to other technologies could affect the number of square meters sold significantly. In turn, this could then cause the sales growth of LED video displays to slow or even perhaps decline.

Any decline in sales for the full-color LED video industry could also have a noticeable impact on the smaller LED display manufacturers that are barely surviving by limiting their ability to achieve reasonable levels of economies of scale that a higher-volume business produces.

Smaller companies struggle

Companies that are not able to attain sufficient economies of scale will be at a disadvantage in buying component LEDs, especially the higher grade LEDs that are necessary for high-quality video images. EDG hears complaints from some of its clients that it is not so easy for them because they are small or medium sized firms and do not have the buying power of an industry leader like Daktronics.

An equal concern of the majority of display manufacturers would be their inability to fill a $50 million order in one year from a large customer such as an outdoor billboard company. This is a definite problem in that most of the companies are too small (75% of manufacturers have sales of less than $25 million per year) to reliably fill orders of this magnitude. Advertising companies who are seriously committed to the concept of advertising billboards, and have billions of dollars in resources, will possibly bypass the display manufacturers, and make or assemble the displays themselves. Though the number of square meters produced would not change, this would however reduce the total display sales in the market.

With the display industry already on shaky financial footing, these factors could have a far-reaching impact on the industry, especially with many of the newer display manufacturers also producing LED components for both the large displays and for other applications. If the success of these companies are based too closely on both divisions working in harmony, then a downturn or financial loss in one could have an adverse effect on the other. This may then cause a ripple effect in the component industry, which is already showing signs of slow growth and extreme competition. Additionally, it is likely to affect the display manufacturing industry by having an unnecessary drain on the resources that are needed to compete in a global market. ●

About the author

Peter L Pihos Jr is a partner in EDG Research and Consulting (www.edguide.com), a firm specializing in the field of large-area displays since 1982. He was the publisher and editor of Electronic Display News *magazine. Prior to starting EDG, Pihos was an intelligence analyst with the National Security Agency (NSA) specializing in telemetry and radar systems.*

High-power LEDs provide illumination and treatment in medical applications

An enormous range of medical applications, from surgical illumination to photodynamic therapy, can benefit from the advantages offered by LED light sources, according to **Gareth Jones** and **Grant Barnett** of Enfis Ltd.

The medical market has traditionally been an avid adopter of photonic technologies, from the use of laser sources for surgical and cosmetic applications to the more traditional use of specialized illumination sources for surgery or examination. The medical market places stringent requirements on the design of medical devices, with particular emphasis on the safety of the patient and operator. LED light sources are a safer and lower cost source of light and, with recent advances, LEDs are well placed to replace other high-power light sources for many medical applications.

The use of light in the treatment of medical and cosmetic conditions is a rapidly growing segment of the treatment market. Light can be used for both active treatment, with or without a drug, and also for sensing or diagnosis of medical conditions such as tumor detection. Treatments associated with the skin (dermatology) and cosmetic treatments are billion-dollar worldwide markets (see figure 1). With the advent of ultraviolet (UV) and white LED light sources, there are a growing number of opportunities in the use of LEDs for medical and dental lighting systems incorporating visible light and diagnostic elements such as UV fluorescence.

Medical applications make use of wavelengths from the UV-C band around 260 nm through to the upper end of the visible region around 750 nm, and also use white light. The needs of white lighting devices in medical applications are diverse, but in general require a stable source of high-quality (high CRI) white light that does not impart heat onto the examination area and is compact, safe and energy efficient. If designed properly, LEDs can be made to suit these requirements.

Examples of medical applications

The medical illumination, treatment and diagnosis fields encompass an enormous range of applications. Many of these utilize specialized light sources to enhance either the illumination level for the surgeon or to induce a response within the body such as fluorescence used to diagnose the presence of certain chemical or biological species. In this article we will describe some of the uses of high-power LEDs, for example:

- Medical lighting for the operating room and home environment;
- Phototherapy for dermatology and neonatal jaundice;
- Photodynamic therapy (PDT) and photodynamic disinfection (PDD);
- Deep-UV LEDs for photobiological disinfection.

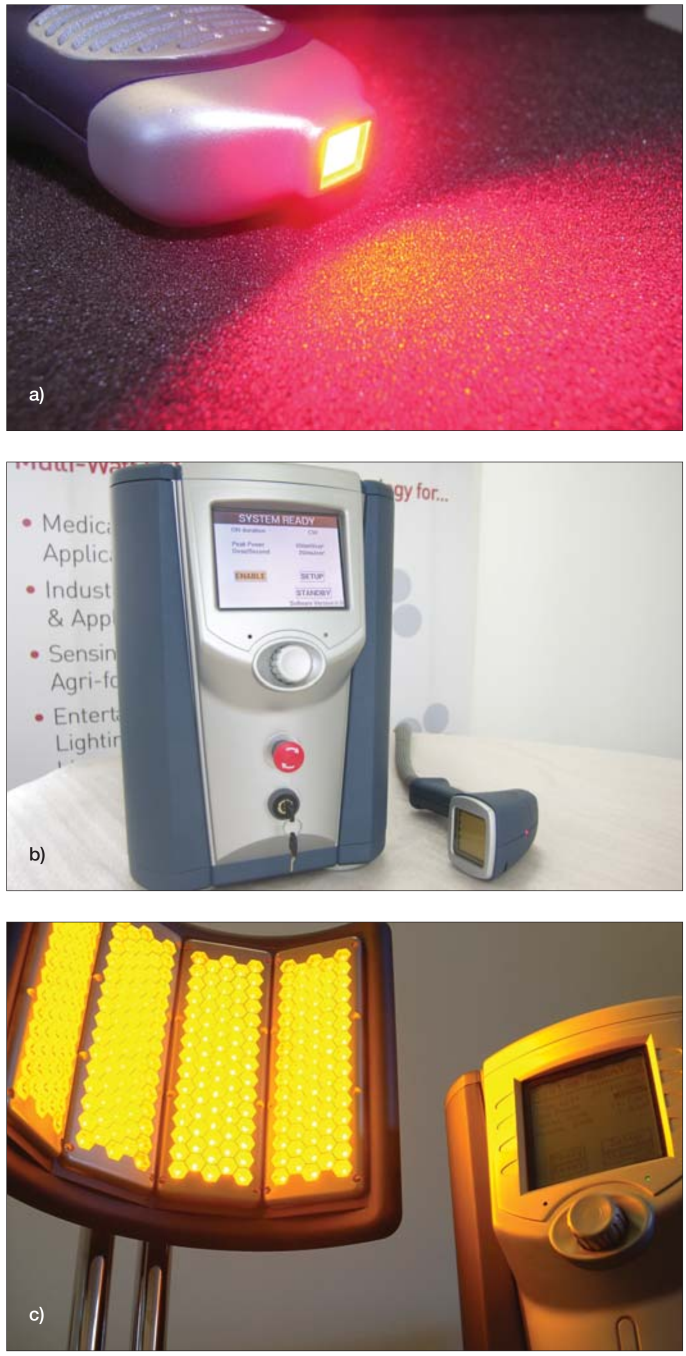


Fig. 1. LED-based systems from Enfis Ltd designed for various dermatological treatments: (a) a portable LED treatment device for use in the home; (b) a very high power-density system for use in a hospital or doctor's surgery; (c) a wide-area illumination system intended for use by doctors or in spas and health centers.

Medical lighting

High-power LEDs provide a number of unique advantages in medical illumination. They provide "cold" lighting, due to a negligible amount of infrared emission, which is a source of large amounts of heat from traditional lighting devices. LEDs also provide the ability to tune the color temperature across a wide range, and the ability to switch between colors quickly. They are generally small, compact and rugged light sources with higher efficiency and therefore lower power consumption than traditional sources, and there is a lack of mercury or glass in the lighting element. LEDs also have longer lifetimes, leading to lower cost of replacement and higher confidence in the lighting solution.

Of course, the use of LEDs in many lighting applications is still in its infancy, with issues still to be resolved, but none of these will prevent LEDs from achieving widespread adoption in the medical illumination fields.

Operating room illumination

Lighting an operating room (OR) places strong safety and reliability demands on lighting systems. LEDs have many technical and practical advantages over conventional halogen and gas discharge lamps, including extremely low radiative heat generation and high reliability, if designed properly.

With some LED fixtures, the surgeon can change the color temperature and maintain a high color rendering index to suit their own personal preferences during surgery. There is no need to filter out any UV wavelengths (since no UV is emitted).

LEDs also have an extremely long lifetime. As an example, halogen bulbs last between 200–1000 hours, while various types of LEDs claim a lifetime of between 8000–50,000 hours. As well as eliminating the need for replacement bulbs, such a long lifetime also reduces the associated down time of the OR room and maintenance costs.

LED surgical lights are already on the market (see figure 2). Systems with multiple (100–200) LEDs purport to emit 120,000–160,000 lux at 100 cm (the maximum light output permitted in many countries) with a color temperature of 3500–5000 K. Many different-colored LEDs populate the lens, enabling the surgeon to change the color temperature and color rendering index (CRI) in the 80–95 range. This is a product benefit to the surgeon when working in a location where there is a weak or heavy blood supply, as the color temperature can be altered for optimal contrast and differentiation.

As LED technology has developed, it is now possible for an OR illumination system to be built around a single multi-watt LED light engine and array. Such innovation may supersede existing "multi lens" systems with the potential for much lower costs and smaller, more maneuverable devices in the near future. The single source will operate in a similar fashion to conventional lighting-based OR systems, but will boast extremely long lifetimes, no IR or UV output, high efficiency, high CRI and the facility to change color temperature as and when required; these are safety and user features that halogen and gas exchange lights are not able to offer.

Lighting for health and well-being

One type of medical application that is gaining widespread interest, especially in Japan, is the use of light sources to provide low-level photobiological influences to people. Such effects include increasing the alertness of shift workers, reducing jet lag for long-haul passengers, and improving the symptoms of seasonally affected disorder (SAD).

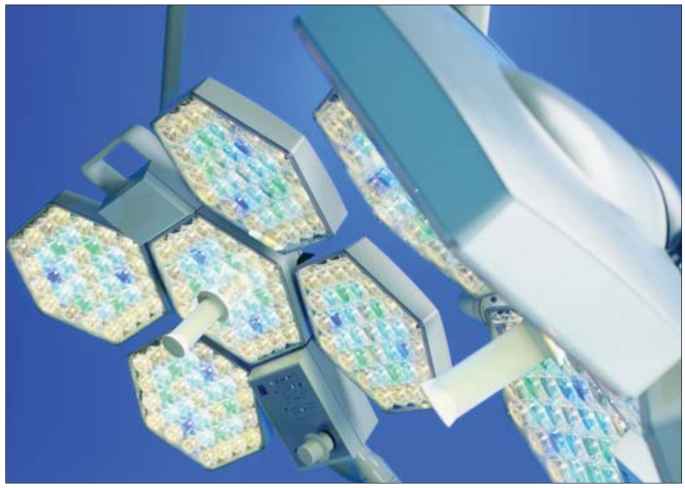


Fig. 2. Trumpf Medical Systems' iLED lighting system, a multi-LED light source for operating rooms that allows surgeons to adjust the color temperature (see www.ledsmagazine.com/articles/news/3/8/4).

Many companies are beginning to recognize the growing importance of lighting as a lifestyle entity and that the use of LEDs can dramatically enhance lifestyle effects. Lighting designers will soon be faced with a basic question. "Is the fundamental objective of lighting to provide an appropriate level of visibility without discomfort, or should we consider the photobiological effects of lighting as equally, and sometimes more, important?"

For many years scientists did not believe that such photobiological effects occurred in humans at the illuminance levels typically used indoors. Researchers thought that illuminance levels of at least 2000 lux were necessary to have any photobiological effect. Recently it has been shown that this is not true, depending upon the time of day that the light is administered, leading to a resurgence in the provision of lighting for well-being enhancement.

Shift work

In the United States and Europe, approximately 20% of the workforce is involved in shift work. Many workers can appreciate the difficulty of working what is called the graveyard shift (typically, midnight to 8:00 a.m.). Basically, you are trying to work when your body is telling you to sleep, and trying to sleep when everyone else is awake. Rapidly adjusting the sleep/wake cycle at the start and end of a series of night shifts, by using light to shift the phase of circadian rhythms, can alleviate this situation. (Circadian rhythms are a roughly 24-hour cycle in the physiological processes of living beings, and are important in determining sleep and feeding patterns.)

To make an economic case for the use of the photobiological effects of light on nightshift workers, however, tests have been performed to demonstrate that being more awake at night affects task performance. Following exposure to bright light, subjects who underwent cognitive performance tests showed improvements in complex cognitive tasks requiring logical reasoning and short-term memory.

Knowledge of these effects has led to the installation of lighting that provides high illuminance levels at times designed to shift circadian rhythms in a number of power-station and chemical-plant control rooms, where alert judgment can have major safety and economic impacts.

Fig. 3. The Litebook LED light therapy product (www.litebook.com) contains multiple white LEDs and treats jet lag, shift-work problems and the winter blues. The *elite* model launches this fall.

Jet lag

A common experience of unsynchronized circadian rhythms is jet lag, the feeling of being out of step with the pattern of life at their destination experienced by people who have traveled across several time zones. Timed light exposure is important for treating jet lag in business people, airline flight crews, and long-distance tourists. It is possible to predict the best times for light and dark exposure to rapidly shift a person's circadian rhythm and, in particular, the sleep/wake cycle.

Seasonally affected disorders

Less immediate effects of light are associated with seasonal changes, commonly manifested as SAD. This is a psychiatric condition in which people experience lethargy, depression, and food cravings during the winter, but not in the summer. SAD can often be successfully treated with exposure to light. Typically, light treatment uses two kinds of devices; the light box and the dawn simulator.

People diagnosed with SAD sit in front of the light box for a predetermined period of time; the higher the illuminance at the eye, the shorter the time of exposure. Conditions for exposure are typically 2500 lux at the eye for two to four hours or 10,000 lux for 30 minutes.

At present, many light-box products use fluorescent lamps (see for example www.lighttherapyproducts.com/products_lamps.html) to achieve the desired illumination levels and spectrum, but developments underway in LEDs sources will provide the same effects with a single source of high-intensity light with extended lifetime and compact form.

One problem with a light box is that it limits the patient's activities during the recommended exposure period, which is daily for several weeks. The dawn simulator is, as its name implies, a device that slowly increases the amount of light in a bedroom while the person sleeps to improve their mood at awakening. Both devices reduce seasonal depression for a number of the people who use them. However, the results of light exposure on seasonal depression provide no widely accepted explanation of the effect; light may be simply a very effective placebo. Although this is a possibility, scientists have demonstrated that both the light box and the dawn simulator alleviate depression more effectively than other relatively low-level lighting conditions designed to act as placebos.

Beyond vision

In the future, designing lighting solely for vision will be inadequate, but to meet this new challenge lighting designers and physiologists will have to meet additional needs. We will need a clearer understanding of the mechanisms involved, particularly for the treatment of depression and for the immediate effects of light such as the effect of lamp spectrum and its effect on the retinal photoreceptors.

It is only when we identify the spectral sensitivity of the active photoreceptors (and the requirements for vision) that we can derive the optimum lamp spectrum. This is where LED sources will become strong players since they are easily made up of many discrete wavelengths and can be added together to fine tune to achieve the best photobiological response.

This section on lighting for health and well-being has drawn upon the descriptions provided by Peter Boyce of the Human Factors Program at the Lighting Research Center in Troy, New York.

Phototherapy and dermatology

Multi-watt LED systems are starting to be used in the medical treatments sector to treat dermatological conditions such as acne, psoriasis and eczema. High power levels are a pre-requisite for efficacious treatments, but cost and safety issues have prevented the effective penetration of laser systems into the dermatology market.

LED light engine technology has been well proven to treat conditions such as mild to moderate acne. Recent trials used an Enfis high-intensity LED source, employing a narrowband yellow LED at 570–600 nm. This is similar to laser-based systems that claim to provide a fast and effective acne treatment. Figure 1 shows examples of LED-based systems developed by Enfis, which are being trialed for various dermatological treatments.

Well-proven clinical results and the safety of LED products means that the use of LED technology in the home environment without expert supervision is a viable prospect within a short timescale. The devices can be battery powered, are eye and skin safe, and are low cost. For many patients they provide a suitable efficacious alternative to conventional pharmaceutical compounds, which might not suit their lifestyle.

There is great interest from dermatologists who see the potential for high-power LED devices being used to treat their patients using UV, visible and infrared wavelengths. To enhance usability, it is now possible to incorporate, monitor and control multiple wavelengths on a single array, thus offering products that are truly differentiated from those available until now to the consumer, beauty therapist or dermatologist.

Treatments associated with the skin are billion-dollar worldwide markets. It is estimated that by 2009 the number of worldwide consumers utilizing light-based devices will increase to more than 12 million, with consumer sales rising to an estimated $1.4 billion.●

Medical applications, part 2

In the next issue of *LEDs Magazine Review*, the authors will look at more medical applications for LEDs, including neonatal phototherapy, photodynamic therapy (PDT), photodynamic disinfection (PDD) and the use of deep-UV LEDs for disinfection.

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