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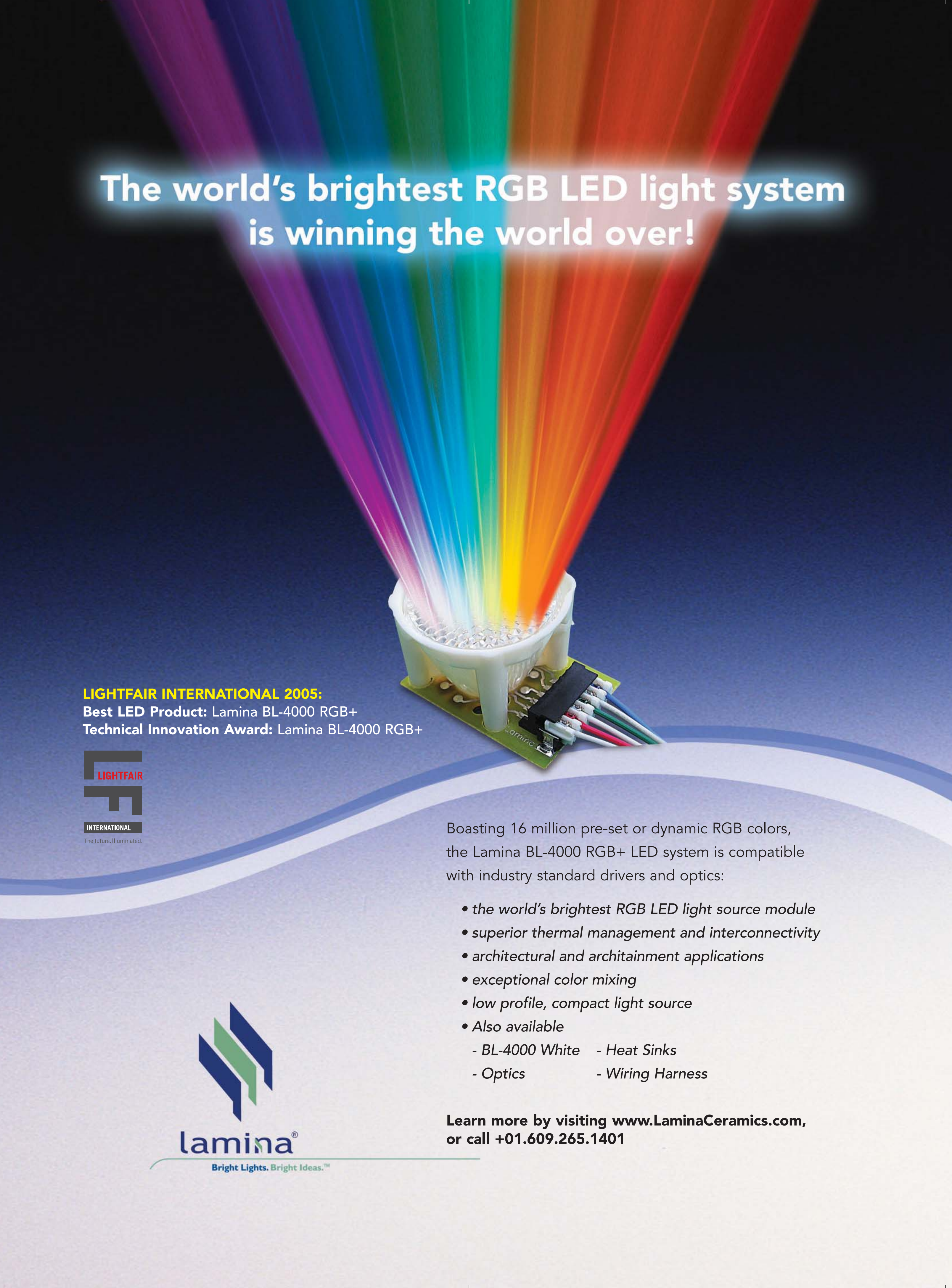

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PATENTS

Super Vision suffers major setbacks in patent battle against Color Kinetics

Super Vision has suffered three straight defeats in the US District Court for the District of Massachusetts in its patent war against Color Kinetics (see box opposite) but plans to keep fighting on behalf of the LED Alliance. The group believes that Color Kinetics has been granted a series of patents that are substantially based on prior art.

Most recently, the lawsuit filed in March 2004 by Super Vision alleging that Color Kinetics is infringing US patent no. 4,962,687 was dismissed. The patent in question was acquired by Super Vision from High End Systems and is entitled Variable Color Lighting Systems. The court determined that Super Vision, rather than being the owner of the patent, was a non-exclusive licensee, and as such had no right to enforce the patent. However, the court did not rule out the possibility of a future lawsuit should Super Vision acquire the appropriate rights from the patent owner.

Super Vision says that it will "review the court's dismissal in depth and file another suit against Color Kinetics". It also believes that the ruling "will have no impact on Super Vision's ability to prevail on the merits of its infringement claims".

Only three weeks previously, the judge issued a summary judgment ruling in favor of Color Kinetics, stating that the company's patents in question were valid and that certain Super Vision products infringed on some of those patents. Super Vision stated that it intends to appeal against this ruling, and is confident that it will have more success in front of the US Patent Appeals Court in Washington. In a message to LED Alliance supporters, Brett Kingstone, president and CEO of Super Vision, wrote "although there can be no guarantee of success, our attorneys are still very confident in our ability to return this case to a jury trial on the merits, based on significant errors in prior rulings both in fact and in law". An appeal (see www.svision.com/enews/transfer/SVResponseCK0905.pdf) has already been filed against the first round of summary judgment rulings that went in favor of Color Kinetics.

With Super Vision planning to appeal against the most recent summary judgment rulings, and also to re-file its infringement case concerning the '687 patent, there is no end in sight. Kingstone told the audience at the recent LEDs conference in London (see p11) that "it could take two more years to resolve everything".

This provides little comfort to the many LED fixture manufacturers on the sidelines of this dispute. However, some are not standing still. At September's PLASA show, Tryka L.E.D. Ltd unveiled its Intelligent Drive System products. These utilize Pulse Amplitude Modulation technology, which has been patented around the world, and represents an alternative to the pulse width modulation (PWM) technique around which many of the contentious Color Kinetics patents are based.

European companies remain concerned, even though a group of them, including Vossloh-Schwabe and Lagotronics, have banded together to challenge Color Kinetics' patent applications in Europe. Third parties can file observations at the application stage or can file an opposition to the patent up to nine months after the patent is granted.

STEVEN RAND

Extreme irony: a total of 81 ColorBlast 12 units from Color Kinetics have been used to illuminate the façade of the new regional European Patent Office building in Munich, Germany. Designed by New York artist Steven Rand, the installation is programed to scan through a full spectrum of 16.7 million colors during the course of one full year, before starting the sequence again.

Three strikes but not out...yet

The US District Court for the District of Massachusetts has ruled in favor of Color Kinetics on three separate occasions in recent months. The rulings relate to the following lawsuits:

- March 2002: SV files lawsuit seeking to have certain CK patents ruled invalid
- June 2002: CK files lawsuit claiming infringement by SV of certain CK patents
- March 2004: SV files infringement lawsuit against CK over '687 patent

Strike 1. Color Kinetics' summary judgment motion granted (April 2005)
Color Kinetics' motion was granted for summary judgment regarding three of Super Vision's claims relating to interference with prospective business relationships, trade disparagement and defamation.

Strike 2. Color Kinetics wins summary judgment rulings (August 2005)
The court ruled that a group of five patents granted to Color Kinetics are valid, and that various Super Vision products infringe on some of these patents. SV plans to appeal in the US Patent Appeals court.

Strike 3. Super Vision patent lawsuit dismissed (September 2005)
Super Vision's lawsuit against Color Kinetics alleging infringement of the Variable Color Lighting Systems patent was dismissed. SV plans to re-file.

Jörn Bielich, managing director of DigitalLicht AG of Freigericht, Germany, has some fairly typical views. "Clients such as architects and lighting designers want to choose from a plurality of manufacturers with a wide range of products," he says. "They want to have an open market with fair competition. If other companies stop developing new technologies and products [because of pressure from CK] then the enormous growth of the LED market will slow down."

Others, such as Jed Dorsheimer, think that the recent rulings in favor of CK will allow the industry to move forward (see p18). Detlef Eobaldt, sales and marketing manager of Lagotronics, has a similar view. "Yes, the CK patents might be obstacles, but so are other patents in other industries," he says. "My intention is to move the industry forward without turning around in circles and leaving the whole thing to the lawyers."

LED SUPPLIERS

Philips takes control of LED maker Lumileds Lighting

Philips is to acquire the 47% stake owned by Agilent Technologies in Lumileds Lighting, the high-power LED manufacturer set up as a joint venture by Philips Lighting and Agilent in 1999. The deal is worth $950 million (€765 million) to be paid in cash on completion. Philips will hold 96.5% of Lumileds' issued and outstanding share capital, with the remaining 3.5% owned by an employee trust company.

Over the 12 months from August 2004–July 2005, Lumileds' sales increased approximately 28% to $324 million and the company had an operating profit of $83 million. Lumileds' headquarters is in San Jose, California, and employs 1,760 people at its offices in San Jose, Penang, Malaysia and Best, and the Netherlands.

Philips' in-house capabilities now extend from LED chips to complete solid-state lighting (SSL) modules and systems. By aligning Lumileds' LED activities with existing LED lighting modules and luminaires manufactured by Philips Lighting, as well as the semiconductor competencies within Philips Semiconductors, Philips says that it will be in an "excellent position to strengthen its leadership position" in this new technology.

The deal provides Philips with access to over 200 LED-related patents, and deepens the company's presence in higher-growth, higher-margin segments of the lighting industry. Philips is targeting 5% growth for its lighting business, which has annual sales of around $5 billion. The contribution from Lumileds, with sales currently around $320 million, is expected to start making an impact in the longer term.

Philips expects to be producing conventional light bulbs for at least another 25 years, if not longer, and says that many of the early applications for LEDs in lighting will exploit specific advantages of LEDs rather than to replace conventional technologies.

PHILIPS

MOONCELL

In July, Philips installed warm-white LED street lights in the Dutch town of Ede. The luminaires contained six 3 W white and 12 1 W amber LEDs. Philips claimed that Ede was "the first municipal council in the world to use lampposts with LED technology for public lighting". However, Mooncell installed 30 LED street lights in Coryton, a suburb of Cardiff, Wales, as far back as 2003. The Econo-Lum luminaires contain 36 1 W LEDs and are mounted on 6 m poles. Mooncell says that it is now trialing a unit with 24 3 W LEDs for the same site.

Competition

Lumileds is the leading manufacturer of high-power (1 W class) LEDs with its Luxeon product line, although it faces increasing competition from Cree's XLamp, Osram Opto's Golden Dragon, Seoul Semiconductor's Z-LED, Cotco's Dorado and of course high-power products from Nichia, Toyoda Gosei and other Japanese LED manufacturers.

The deal will bring Philips' SSL sales more in line with its European lighting rival Osram (part of Siemens). Osram had sales of €4.2 billion in 2004, of which 11% (around $570 million) came from its Osram Opto Semiconductors unit as well as LED sales from other divisions. However, it is worth noting that only a small proportion of this revenue came from the lighting market.

Another lighting giant, General Electric, has a much smaller SSL division, GELcore, which is a joint venture with Emcore, a semiconductor materials specialist. GELcore had revenues of around $70 million in calendar year 2004, and was profitable. The company's anticipated revenue for 2005 is around $90 million. Most of this revenue comes from traffic lights, channel letters and other signage and display products.

Once the Philips deal is completed in the fourth quarter of 2005, both it and Osram will be fully vertically integrated with in-house chip fabrication, LED packaging, module manufacturing and system integration. In contrast, both Nichia and Cree are independent companies that manufacture chips and packaged devices, but don't have integration further up the supply chain. Cree's LED revenue for the fiscal year ended June 2005 was $322 million, almost all of which was for unpackaged chips. Nichia, the world's largest LED manufacturer, had LED sales of approximately $1.225 billion in 2004. Toyoda Gosei, another leading LED supplier, which is based in Japan and is part of the Toyota group, expects to generate total sales from LED products of $225 million in 2005.

Vertical integration

Philips executives were keen to stress the benefits of vertical integration, citing synergies in marketing and manufacturing which could lead to enhanced productivity and cost savings. The benefits of bringing an entire supply chain in-house, rather than outsourcing certain aspects, depend largely on the maturity of the technology. While applications for mobile phone handsets are relatively mature, the applications targeted by Philips, such as LCD backlighting, automotive headlights and of course general illumination, are at a very early stage of development. This presents the opportunity for rapid innovation within an integrated supply chain.

Perhaps the most revealing segment of the press conference announcing the Lumileds deal came when Philips management team spoke about the enhanced influence that Philips will be able to exert over the LED development activities of its soon-to-be in-house supplier.

But where will this leave external customers? Small companies using low volumes of Luxeon devices – companies which Lumileds has been happy to serve in the past in order to get the technology out into many varied market segments – may feel the squeeze when Lumileds' attention becomes focused on its giant parent. Lumileds is of course keen to stress that this will not be a problem, and Mike Holt, the company's CEO, said that Lumileds' customers will "remain unaffected as the company moves forward".

At the recent Next LED Generation conference in London (see

page 11), a panel session discussed how to bridge the gap between OEMs and lighting designers. One participant expressed the hope that the integration of Philips and Lumileds could result in the development of standard formats for presenting this information. Over to you, Philips…

NATIONAL PROGRAMS

US Energy Policy Act provides funding for solid-state lighting

The US government has finally passed the Energy Policy Act of 2005, which will provide significant levels of funding for the development of white LED lighting technology. This is the culmination of several years of political maneuvering involving many interested parties.

The Act authorizes the formation of the Next Generation Lighting Initiative (NGLI), a public–private partnership which could provide up to $50 million annually to develop solid-state lighting. The NGLI authorizes the US Department of Energy (DOE) to receive a significant level of funding for solid-state lighting, and also instructs the DOE to work closely with industry to ensure that the fruits of its development program are ultimately turned into products that save energy.

At present, the DOE operates a successful Solid State Lighting program, which funds a large number of projects relating to LEDs and OLEDs. Unlike many activities authorized by the Act, the NGLI is already in good shape; it has already formed an alliance with industry (the NGLIA, or Next Generation Lighting Industry Alliance) and has also signed an Exceptional Circumstances provision covering intellectual property.

The Act requests funding for the NGLI of $50 million per year for fiscal years 2007 (beginning October 2006) to 2009. There is also an extended authorization to allocate $50 million for each of the fiscal years 2010 to 2013. However, the exact amount of funding that would go to the DOE is set by an appropriations committee. In other words, although the legislation is very supportive of the NGLI, the higher budget is still not yet in place. For fiscal 2006, commencing October 2005, the budget is likely to remain roughly flat or increase slightly from the fiscal 2005 level of $12.7 million.

Clearly, an increase to $50 million per year would have a significant effect on the scope of the DOE program. Each year, the program holds a workshop (the next one is in February 2006), and one of the outcomes of these meetings is a list of priorities for R&D work. With more funding the program will be able to support more proposed R&D projects, and will also concentrate heavily on commercialization strategies. These activities will pace the way for solid-state lighting to hit the ground running when it finally starts to penetrate the general lighting market in a few years' time.

Links

Solid State Lighting program: www.netl.doe.gov/ssl
Energy Policy Act (see Section 912 on pp587–91)
www.energy.senate.gov/public/_files/H6_EAS.pdf

On our website:
Industry groups and programs, markets and regional news
www.ledsmagazine.com/articles/features/1/5/10/1

Hella demonstrates white-LED headlamp technology suitable for production cars in 2008

By 2008, all the major technical and regulatory barriers to implementing LED headlamps in production vehicles will be overcome. *LEDs Magazine* spoke with **Norbert Schiermeister**, who is head of LED development for front-lighting applications at Hella.

The IAA motor show in Frankfurt, Germany in mid-September is a traditional venue for car makers and tier-one automotive suppliers to unveil their next-generation technology. This year, as in recent years, LED lighting was featured prominently. For example, Ford unveiled its iosis concept car, which uses LEDs for all the exterior signaling and lighting functions. Hella KGaA Hueck & Co, a leading lighting-systems manufacturer, chose IAA to display a prototype LED front-lighting fixture (figure 1), which demonstrated several technologies and the levels of performance that will be achievable by 2008.

Hella has a long history of working with LED lighting, and earlier this year won an award for its LED front headlamp developed in co-operation with Volkswagen (figure, 2 p8). Norbert Schiermeister, head of LED development for front-lighting applications at Hella, is confident of the widespread penetration of LEDs into forward lighting and signaling functions. "I think in the future we will see a lot of signal functions in LED technology in the front area," he says.

Penetration of LED forward lighting is likely to take a similar amount of time to xenon technology. "It took more than 10 years for xenon to penetrate the market," says Schiermeister. "Similarly, it has taken many years for rear combination lamps [RCLs] using LEDs to reach compact-class cars such as the VW Golf Plus." This vehicle uses a stop, tail and flasher RCL manufactured by Hella (figure 3, p8).

Even so, we should see LED headlamps before too long. "Perhaps there will be first applications of full-LED headlamps in the premium class in 2008 or perhaps earlier in the SAE area," says Schiermeister.

LED headlamps are permitted in the SAE region, which includes North America and Canada, but not yet in the ECE region, which covers Europe and Asia. However, this appears to be only a matter of time, says Schiermeister. "By 2008, I think that there will be approval in the ECE region and all major technical barriers will be solved."

IAA prototype

The prototype shown at IAA uses a number of LED arrays developed by Hella in co-operation with its Japanese partner, Stanley Electric, as well as specially designed Cartoval lenses (the name Cartoval comes from Cartesian and oval; these are oval-shaped lenses produced on the basis of a Cartesian mathematical equation). As shown in figure 1, five solid plastic lens modules are arranged next to one another in the upper part of the headlamp, and these produce the low beam. For the high beam, two additional modules are switched on; these are positioned vertically on the outside of the headlamp.

Fig. 1. The prototype LED headlamp developed by Hella and Stanley features seven Cartoval lenses in front of multi-chip white LED arrays which provide the low- and high-beam functions. A homogeneously illuminated white "LED curtain" acts as the position light, while a dynamic bending light is incorporated into the bumper.

Each of the modules contains a four-chip white-LED array developed by Stanley and Hella. The new headlamp has been designed in such a way that by the year 2008 its light output will equal that of a xenon headlamp. Schiermeister says that this takes into account the continual increase in luminous output of white LEDs, as described by the LED makers' roadmaps.

Also within the headlamp, positioned between the two high-beam

Fig. 2. Hella's earlier LED-headlamp prototype, demonstrated on a VW Golf, achieves a luminous flux of nearly 1000 lm in the low beam. The headlamp recently won a top award for innovation at the Barcelona Motor Show.

Fig. 3. Hella has supplied rear combination lamps (RCLs) for the VW Golf Plus. Each outer lamp has two concentric rings containing a total of 36 red and red-amber LEDs. Different combinations of these LEDs create the tail lights, brake lights and indicators.

Fig. 4. The Audi A8 W12 has a daytime running light comprising five white Luxeon LEDs in a distinctive clover-leaf pattern.

modules, are two standard white LEDs behind small rectangular plastic optic elements. These, together with the dimmed high-beam modules, produce the required light distribution for the daytime running light (DRL). Hella prefers to use a dedicated DRL and in fact the company has supplied the first LED-based DRL for a production car, the Audi A8 W12 (figure 4).

The prototype also incorporates a so-called "light curtain" as the position light. In figure 1 (p7) this is seen as the white area extending below the low-beam modules and around the high-beam modules. The light from several concealed LEDs (standard white devices) is coupled into a light-guiding plastic plate and is distributed evenly on the inside of this plate by reflection. The plate contains light-scattering outcoupling elements that direct the light to the front. "The effect is that we get a very homogeneous appearance," says Schiermeister. "The plate can be shaped in many different ways, and can follow the contours of the headlamp. This allows us to create new brand-specific and customer-specific identities." In the IAA prototype, the direction indicator comprises seven standard amber LEDs arranged behind the light curtain; when the indicator and position light are switched on together this produces a highly distinctive appearance.

Bending and cornering lights

The IAA prototype also demonstrates a cornering light, which is incorporated as a separate module into the lower part of the bumper. Four Cartoval plastic lenses arranged next to one another are aligned in different directions and dynamically direct the light of the LED assemblies behind them. Hella is also investigating systems that will allow dynamic light distribution.

Cornering or bending lights provide illumination around tight curves or when the car is making a turn maneuver. The light is controlled by the front turn indicator, the steering angle and the car's forward speed.

Schiermeister explains that cornering and bending lights are different. "In a cornering light, the complete system is switched on or off," he says. "Cornering lights using LEDs already have SAE and ECE approval. For a bending light already in production, the complete module, together with the low-beam illumination pattern, is swiveled"

In some current production vehicles this is done with a mechanical system, using stepper motors and a control unit. Clearly, the use of LED technology could eliminate the mechanical elements. In principle, different switch-on algorithms can be realized using the electronic controls. Thus, for example, all four elements can be switched on together depending on the speed and steering angle and then be dimmed down again. Alternatively, dynamic step-by-step activation of the four elements is also conceivable. This makes it possible to optimally adapt this additional safety light to the bend situation. Schiermeister says that in future, LED main headlamps may incorporate bending lights as well as the low- and high-beam functions. "We have built prototypes and have investigated their appearance on the street, looking at their different dynamic effects and control modes," he says.

Thermal issues

The use of many high-power LEDs in a confined space within a car headlamp creates thermal-management issues, since the performance and life expectancy of an LED drops considerably when it is operated at a high junction temperature.

Hella's IAA prototype solves this with cooling fans. "When these headlamps enter series production, probably in 2008, in our opinion

we would have to use one fan for each headlamp," says Schiermeister. "But looking to the future, we see that LED efficiency increases from year to year, and light output per watt becomes better every year. It seems likely that in 5–6 years' time we won't need a fan at all."

LED suppliers are also working on products that can operate at a higher junction-temperature specification, moving from around 130 °C to 180 °C. But in the shorter term, are fans OK for a production vehicle? Schiermeister says yes, although these would be specially developed fans, rather than standard ones from a PC for example.

"Increasing the efficiency of the LEDs will lead to a significant reduction of packaging space for a full-LED headlamp," says Schiermeister. "However, today you can certainly gain space savings by converting signal lamps to LEDs. It's possible to design a front indicator, position light or side marker that is much smaller than using incandescent technology." An example is the BMW 5-series side marker, where the motivation was space savings and also styling.

In practice a big advantage of LEDs is that you don't have to anticipate the possibility of changing the light source, while with incandescent bulbs there needs to be the means to change these when they fail. Nevertheless, it's likely that the regulation committee working on the new ECE regulations will want to avoid the situation that if one LED fails you have to throw away the whole headlamp.

"I think it's likely that the ECE regulation, when it comes, will include a requirement that it must be possible to change the LED module, perhaps only with special tools," says Schiermeister. "In practice, however, this won't be necessary. LEDs are very robust, and based on many years of working with LED-based center high-mounted stop lights (CHMSLs) we know that if you design the PCBs correctly and guarantee to drive the LEDs within their specifications then there should be no problems."

Advantages and barriers

Some advantages of LEDs have already been mentioned, and others are listed in "Advantages of LEDs". Even with these many positive points, there remain various barriers. Cost is certainly an issue, and will likely remain so for a while. Pricing is still a major barrier in rear combination lamps; everyone wants to use LEDs, but they are still more expensive than normal bulbs.

Regulatory approval is only a matter of time, says Schiermeister – car makers can already use full-LED headlamps in the SAE area, and full ECE approval is expected in time for 2008. Today in the ECE region LEDs can be used in the front headlamp for signal functions – DRL, position light, front indicator – but not for low beam, high beam and fog lights. Since LEDs are a new light source they require regulations, but there are no barriers that cannot be overcome, says Schiermeister. "Teams are working on this issue, but it takes a lot of time: there are lots of suppliers and customers that need to be consulted." In terms of technical challenges there are a number of issues, such as thermal management, but as discussed above LED efficiency is expected to improve, and the performance roadmaps indicate that the situation will improve.

Roadmaps also call for higher luminous flux, higher luminance and of course lower cost. In the VW Golf headlamp shown in figure 2 (p8), the luminous flux is 960 lm, which is near to the value that can be achieved with xenon technology. However, illuminance remains a problem, and doesn't reach xenon values. "For this reason, high beam using LEDs is currently not as effective as a xenon module," says Schiermeister. "But if LED manufacturers stick to their roadmaps, then LED high beam will be comparable with xenon in 2–3 years' time."

The automotive market often has special specifications, but LED manufacturers are already familiar with this situation. ECE and SAE regulations define color of white light within a specific window. "We work with LED makers to define special color binnings, within which we can't recognize differences. Sometimes LED makers don't like it because they want to sell us everything from their production runs, however this is not acceptable in the automotive market. Although this system is already established, LED makers need to work harder to focus their production within the allowed window." ●

Advantages of LEDs

According to Norbert Schiermeister, there are several key advantages of white LEDs for forward lighting, and their relative importance depends on function:

- service life exceeds vehicle life;
- space savings: this is an immediate advantage for signal functions, and a medium-term advantage for low- and high-beam lighting;
- styling options: LEDs don't produce infrared radiation, so the devices can be placed directly behind a plastic optic element. Along with the ability to arrange the light sources in a variety of ways, this presents new possibilities to style the complete headlamp;
- low energy consumption: a DRL using low beam can consume more than 150 W. However, we can create a DRL using three standard 1 W LEDs. Even allowing for power for the control unit, this would only consume 4–5 W for each headlamp, or 10 W for each car;
- light color: this advantage was realized when we built the prototype for VW. Compared with halogen or xenon, the light color of white LEDs is near daylight, which is very comfortable for the driver, especially for the main headlamps. Or if you realize an LED position light or DRL in combination with a xenon module, this combination works much better than halogen with xenon; and
- intelligent light functions such as dynamic bending lights are possible because the LED is a semiconductor and can be dimmed, or switched on and off very quickly. In our research department, we are thinking of a multi-chip array using 30–35 chips, where every chip is addressable, and which can produce every light distribution by switching different combinations on or off. We are looking for an application in the 2010–2012 timeframe.

Links

Hella: www.hella.com

On our website:

Vehicles channel
www.ledsmagazine.com/articles/features/1/5/4/1

Hella earns auto prize for LED headlamp concept
www.ledsmagazine.com/articles/news/2/8/6

Two-in-one tail lights feature in new VW Golf Plus
www.ledsmagazine.com/articles/news/2/5/8

LEDs in the mainstream: technical hurdles and standardization issues

A recent conference in the UK focused on the latest developments in LEDs and the ways in which they can be moved into the mainstream lighting market. **Tim Whitaker** reports.

One of the key issues addressed at the Next LED Generation conference held in London, UK, in mid September was how to bridge the gap between OEMs and end users. Kevan Shaw, managing director of Kevan Shaw Lighting Design, listed the key pieces of information that lighting designers need to know:

- the actual light output of an installed system;
- a realistic estimate of installation life, based on the ASSIST criteria for example (see www.ledsmagazine.com/articles/features/2/4/5/1);
- the repeatability of performance for future replacements;
- honest and accurate efficiency figures;
- that data are presented in a format that can be compared with other light sources;
- specific conditions or issues relating to installation and safety and;
- a method of reliable binning specification in order to maintain visual color integrity.

LEDs, said Shaw, have suffered from marketing hype, with manufacturers overstating reality to differentiate their products, and with prices remaining high so that R&D costs can be recovered. Another issue is that manufacturers provide products at different levels of integration. Some provide dies or simple encapsulated packages; others supply ready-to-install LED packages; other companies use a chip-on-board approach to integrate numerous dies into an array; and some of course produce complete systems including some drive electronics. "Each variation in integration makes it harder to make direct comparison between products," said Shaw.

Specifying LED-based fixtures is a difficult task. "Product-based specification is inadequate, since the same product varies according to operating conditions," said Shaw. "Meanwhile, performance-based specification is hampered by the lack of directly comparable data."

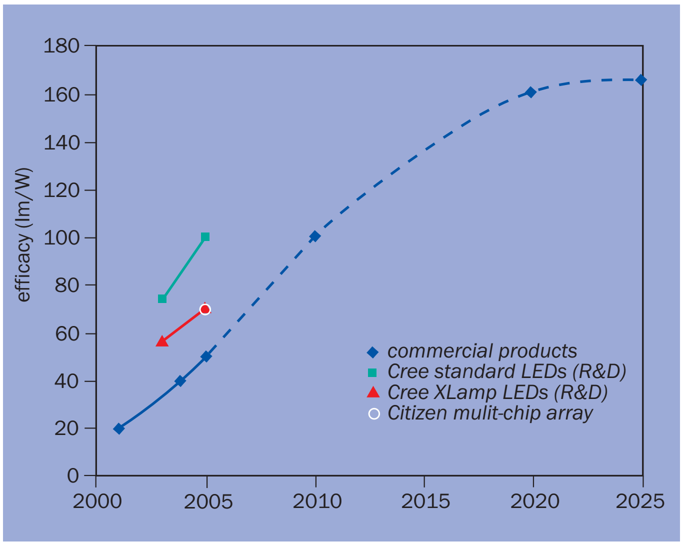


Fig. 1. Latest efficacy results and current and projected market values ("commercial products" values taken from the US DOE Solid-State Lighting program workshop report, February 2005). In the lab, Cree has demonstrated small chips in 5 mm packages with 100 lm/W efficacy (Feb 2005) as well as XLamp power packages with 70 lm/W efficacy and luminous flux of 86 lm (Aug 2005). Earlier this year, Citizen Electronics demonstrated a 70 lm/W white LED with an output of 245 lm. The package measures 40 × 4 × 0.75 mm and contains 24 standard-size (0.3 × 0.3 mm) chips.

Color quality

Kevin Dowling of Color Kinetics described some of the many issues – binning, scaling, color temperature, calibration, specifications, photometry – that make specifying LED systems such a complex exercise.

Dowling complimented LED makers on their considerable achievements in improving their manufacturing processes, but the demands remain stringent, not least to produce white LEDs within narrow bins. Binning is necessary because LED chips are produced on small 2- or 3-inch diameter circular wafers and there is considerable variation in chip performance, in terms of wavelength and intensity, across these wafers.

As Dowling explained, it is possible for a fixture manufacturer to overcome this variation problem by purchasing LEDs from several bins and using "statistical optimization" to select the correct combination of LEDs for each fixture, such that the variation between fixtures is minimized. But why not purchase from a single bin? "Manufacturers would not be able to sell their full production output, so their yields would plummet, and prices would rise dramatically," said Dowling.

Measuring the output of LED fixtures is important, explained Dowling, since "adding up the lumen count on individual LEDs does not equal the total output of the fixture". The complete fixture must be measured according to traceable standards, unfortunately these don't yet exist but efforts are underway through groups such as IES. "We also need this for the LEDs themselves," said Dowling.

White-LED performance

Jeff Lagaly of Cree Lighting, one of the leading LED-chip manufacturers, showed that the company's R&D results for efficacy of white-LED packages are actually ahead of various industry roadmaps for the evolution of lm/W values (figure 1). Cree has demonstrated 70 lm/W packages for power chips and 100 lm/W packages for small chips. These values are starting to compare favorably with many other light sources, and are improving year on year.

Lagaly identified various early adopters for Cree's high-power white

Fig. 2. The Aztec LED Light Engine from Marl contains a 5 W Lamina source and features an optimized heat-sink design.

LEDs in different lighting markets: residential lighting, such as under counters or cabinets (see Cyberlux article, page 27); personal lighting, for example flashlights; sign backlighting; and low-bay illumination.

Lagaly then went on to encourage lighting designers to question traditional lighting solutions, focusing on how much light is actually needed and where, and also on long-term impact. “LEDs can go places filaments never dreamed,” he said.

Drivers

Gordon Routledge of Lumidrives advocated the development of high-end LED drivers that can utilize feedback in the form of current, temperature, optical and temporal data. Taking the last of these, a simple system could increase the driver current over time to compensate for an LED’s decrease in luminous output through its lifetime. The feedback loop could also benefit from external control such as DMX, Dali and photocells.

“Drivers can help to control many LED variables and solve problems that LED makers can’t solve,” said Routledge. Increasingly sophisticated drivers are needed for demanding applications, and, as these mature, more value is likely to be embedded in the driver portion of the fixture.

Thermal management

Jim Anderson of Lamina Ceramics discussed the importance of thermal management and ran through the basic considerations, such as minimizing thermal resistance from the LED chip to the ambient, and optimizing the design and orientation of heat-sinking fins. Several design examples of luminaires were given, including the Aztec LED light engine from Marl (figure 2).

Clearly, in the near term, heat sinking is desirable and necessary, but Anderson then went on to ask, “Will future LED sources need heat sinks?" This will depend on numerous factors such as the future performance of LEDs and their sensitivity to junction temperature rises.

The US DOE has predicted that in 2020 warm white-LED light sources will have an efficacy of 160 lm/W, and will produce about 50% heat and 50% light. To replicate the light output from a 60 W incandescent producing 1100 lm, a 6 W LED source will be required, which will produce 3 W of heat. However, replacing a 400 W metal-halide lamp producing 30,000 lm would require a 190 W LED source, which would generate 95 W of heat.

"In the long term," said Anderson, "High-flux applications will require multiple luminaires or multiple LEDs per luminaire. Heat sinking may not be necessary … but it will be desirable."

Optical design

Optical design, according to Andrew Dennington of Carlco Technical Plastics, is the task of "designing optical components that will take light from the source to the area you want to illuminate, and keep it away from areas you don't". With this in mind, Dennington went through a series of options, ranging from simple lenses and reflectors to light boxes, free-form optics and diffusers, discussing the pros and cons of each approach and offering various design tips. "Optics that were designed for conventional light sources are unlikely to give good performance," he said.

Designers also need to be realistic about the lumen output from the LEDs. "As a practical rule, customers only get 70% of the lumens out that they expect," said Dennington, adding, "a design that only just works on paper is unlikely to work in the real world."

Patent issues

The most eagerly anticipated talk of the day was from Brett Kingstone, Super Vision International's president and CEO, who discussed the company's ongoing patent dispute with Color Kinetics (see page 3).

Kingstone highlighted many examples that appeared to illustrate that some of the inventions claimed within Color Kinetics' early patents were, in fact, based on prior art. Crucially, of course, despite Super Vision's efforts, a court has yet to rule in favor of this hypothesis.

Although the color-change LED patents granted to CK have proved restrictive to their competitors, there is potentially more trouble ahead in the form of patent applications relating to white light. "These patents will have far-reaching complications beyond our current concerns with RGB LED lighting systems," said Kingstone.

One example is US patent application 20050040774, filed October 2004. Claim 1 of 94 states, "A method of providing illumination in a marketplace, comprising: a) generating radiation using a plurality of LEDs, the radiation comprising essentially white light and having an adjustable spectral content; b) illuminating at least one article in the marketplace with the generated radiation; and c) controlling the spectral content of the generated radiation."

In conclusion, Kingstone asked "How does our industry prevent one company from dominating by holding IP on prior art?" The industry has yet to find an answer. ●

Link

Brussels conference sprouts better understanding of LEDs
www.ledsmagazine.com/articles/features/1/11/7/1

EPO aims to improve patent classification in LEDs field

Having seen a steep increase in the number of patent applications related to solid-state lighting, the European patent office is now taking steps to improve its classification to accommodate this new technology. *LEDs Magazine* talked to **Johan van der Linden**.

The European Patent Office (EPO) is currently engaged in two major projects to improve its classification of patents relating to LEDs. As Johan van der Linden, an EPO patent examiner and chief documentation manager for this technical field, explains, patents are a very important source of information on prior art. "Classification – indexing of documentation according to a worldwide agreed scheme – is paramount in retrieving this information," he said. "The alternative is to use keyword searches, which can take a very long time, and can also lead to relevant documents being missed."

However, van der Linden admits that at present, patent classification in the area of solid-state lighting is not transparent. "We are trying to deal with this situation via a dedicated project," he said. "Internally, this will provide us with better prior art searches and allow us to build improved statistics."

In addition to its own Solid-State Lamps project, the EPO is also involved in a Trilateral "Harmony" project with the Japanese and US patent offices to generally improve patent indexing in the area of LEDs.

The European Classification system (ECLA), which is used by the EPO for carrying out patent application searches, is built on top of the International Patent Classification system (IPC), with both constantly being revised and updated. The EPO has a more refined indexing scheme; the current edition of the IPC covers about 70,000 groups, while ECLA covers close to 130,000 groups.

The ECLA system includes the following classes:

- H01: basic electric elements
- H01J: electric discharge tubes or discharge lamps
- H01K: electric incandescent lamps
- H01L: semiconductor devices
- H01L33: semiconductor devices with a potential barrier (i.e. diode structure) adapted for light emission.

The H01L33 group contains many sub-classes covering areas such as arrangements for light extraction or for cooling. The IPC system currently does not contain such detailed sub-groups, and extending the H01L33 scheme in line with ECLA is the focus of the Trilateral Harmony project mentioned above.

Solid-State Lamps project

The EPO's Solid-State Lamps project aims to evaluate whether these light sources represent a technological development important enough to give them the same status as other lamps at the H01 level. Solid-state lamps are defined as an electrical light source using a semiconductor element for light generation. This can be a retrofit lamp containing LEDs, laser diodes, or a completely new solid-state solution.

"Classification is paramount. Keyword searches can take a very long time, and can also lead to relevant documents being missed."

Johan van der Linden

The EPO has recently started to use F21K7/00 ("light sources not otherwise provided for") as an interim class. "The goal is to use this classification systematically and prove its worth," said van der Linden. "In the case that this technical field continues to boom, we will seek to create a new class at the H01 (new electrical elements) level – a procedure which takes time."

Van der Linden says the odds are that this area will grow enormously. "We have been paying great attention to solid-state lighting at the EPO for the past two years as we were experiencing a steep increase in related patent applications. Since the Solid-State Lamps general illumination technology does not match any existing IPC classification, we could foresee a lot of dispersed documentation and time-consuming file allocation in front of us."

The Solid-State Lamps project aims to make the EPO more nimble in dealing with a growing number of applications, not only for retrofit solutions, but also for completely new types of lamp fittings and optics in the longer term.

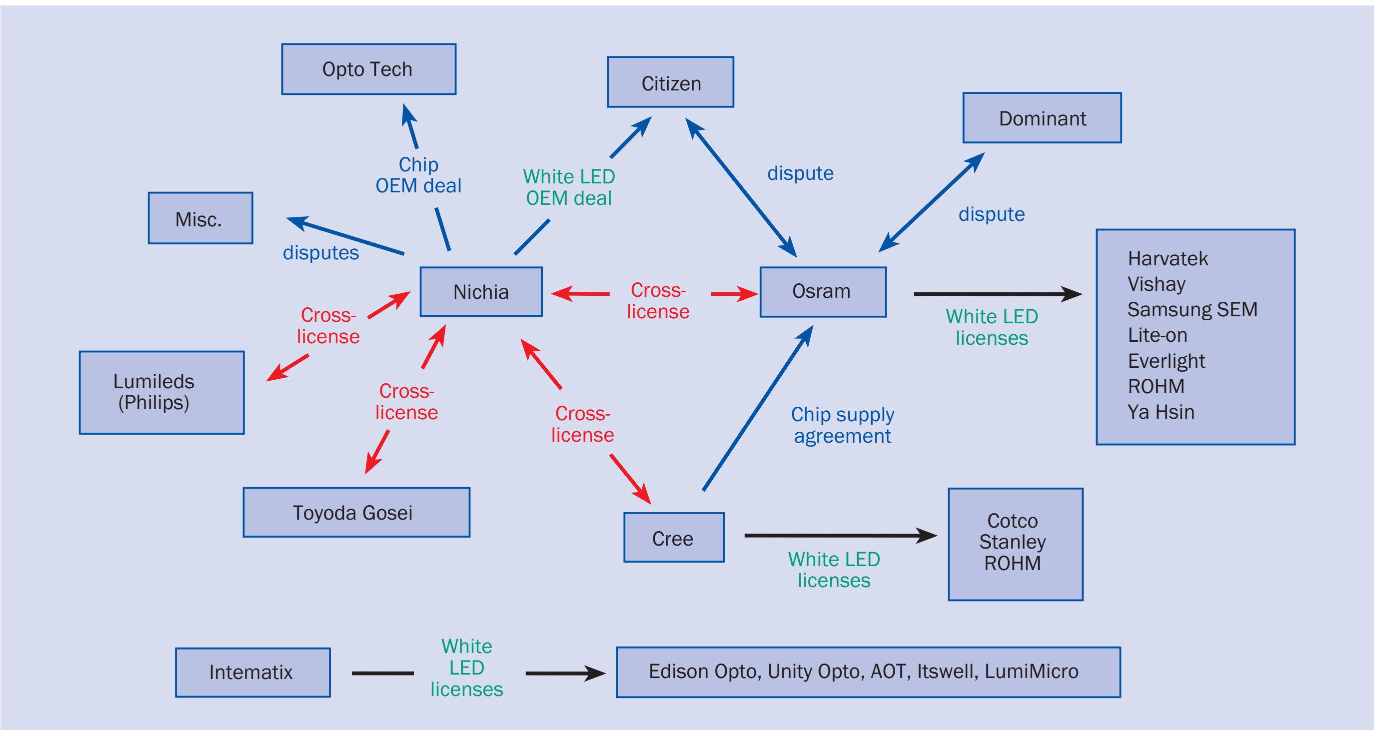
Link

Search page for European Classification system: http://v3.espacenet.com/eclasrch?CY=ep&LG=en

On our website:
Patents & licensing channel
www.ledsmagazine.com/articles/features/1/4/8/1

Small companies fight for a foothold in white LED sector

The white LED area is a minefield of patents, cross-licensing agreements and infringement lawsuits involving the big five manufacturers. **Andrew Phillips** of phconsult Ltd reports on a situation that can prove extremely daunting for new players entering the field.



Deals and disputes in the white LED industry: the key intellectual property relationships as of September 2005.

Until recently, barely a month went by without news of a patent dispute between two or more of the "big five" LED manufacturers: Nichia, Osram, Toyoda Gosei, Cree and Lumileds. Several bipartite cross-licensing agreements between these major players finally stopped the disputes (see figure above), making life much easier for them – but more complicated for the rest of the industry.

The agreements cover a number of aspects of the technology of solid-state lighting, but the most significant for the development of the field are those concerned with color conversion of blue and UV LEDs using phosphors to create white light. As a result, the major players no longer have to argue among themselves over which of their various patents are valid, and are free to turn their attention to possible infringements of the patents they hold, and to license their technology to "second-tier" companies.

Unfortunately, the agreements did nothing to clarify the IP position, or to decide which of the patents are valid, and which have priority. Reading the patent literature reveals an extraordinarily complicated series of overlapping and apparently conflicting US patents (see box, p16). Various rulings have been made concerning patent infringements, some confirming that patent infringements have occurred and others rejecting the claims, but so far only very limited rulings have been made concerning patent validity.

It is not even clear what has been patented in many cases. It would appear that there are no valid patents covering the basic principle of color conversion, given the 1970 US patent for conversion using a screen, and the rejection of the 1991 Nichia patent application for the specific case of an encapsulated blue LED with a fluorescent dye (see box). It would be interesting to know the basis of rejection, or if anyone was objecting to the patent on the basis of prior art while at the same time filing for an equivalent patent in the US.

Comparing the various patents suggests that the nature of the phosphor could be a key issue – see box, p16. (Before the cross-licensing

Key US patents covering white LEDs

The history of white-light LEDs is surprisingly complicated, given the fact that Nichia first produced white LEDs commercially in 1996. Key patents, mainly US, are listed below in order of priority filing date.

- Bell Labs was granted a US patent (3,691,482) on the use of a screen containing one or more phosphors, illuminated with a laser source to give white or colored light, and so establishing the basic principle of wavelength conversion. The patent was filed on January 17 1970.
- Nichia filed for a Japanese patent (Kokei 5-152609) which describes LEDs with a fluorescent dye added to the resin moulding on November 25 1991. It was published on June 18 1993, but the application was rejected on 23 June 1998 and the patent application withdrawn on December 2 1999.
- Cree has ownership of patent 6,600,175 (originally granted to ATMI) with a filing date of March 26 1996, and which was granted on July 29 2003. This patent claims a light-emitting device consisting of a single LED with a down-converting phosphor to produce white light, which attempts to cover almost everything. However, claim 1 refers only to excitation of the phosphor by a source outside the white-light spectrum, which would appear to exclude the usual blue LED and yellow phosphor combination. The Nichia application is included in the references but not discussed, and no specific mention is made of garnet-based phosphors.
- Osram patent 6,245,259 was filed in the US on August 29 2000 and granted on June 12 2001 but had an international patent priority date of June 26 1997. Since then there have been a succession of overlapping patents. The original patent specified a blue, green or UV LED with a cerium- or terbium-doped garnet or sulphur-substituted garnet phosphor. There was no mention in the prior state of the art of the existing commercial Nichia white LEDs, or of the original Nichia Japanese patent application. A key element of this patent appears to be the specification for the mean phosphor particle size, which should be less than 5 µm.
- HP (now Agilent) patent 5,847,507 has a filing date of July 14 1997 and was granted on December 8 1998. The description actually refers to the existing Nichia products, and the key claim appears to be in the way in which the phosphor is applied. A wide range of potential phosphors are included.
- The first Nichia US patent 5,998,925 on white light LEDs was granted in the US on December 7 1999 with a filing date of July 29 1997. It has since been incorporated into subsequent Nichia patents 6,069,440 and 6,614,179 on essentially the same topic. As expected the patent refers to a GaN LED with a garnet-based phosphor, describing the Nichia commercial white LEDs. There is a certain irony in the fact that the first commercial supplier of white LEDs has the latest priority date, although the Nichia US patent publication refers to their previous earliest "patent" (without mentioning that it was a rejected patent application).
- Toyoda Gosei, with Tridonic and others, owns US patent 6,809,347on the use of blue or UV LEDs with alkaline-earth ortho-silicates doped with Eu phosphors. This patent, with a priority date of December 28 2000, was granted on October 26 2004. It appears clear-cut, focusing on a specific phosphor, and so is much less ambiguous than some of the others.

agreement, a claim by Nichia against Osram for infringement of Nichia's Japanese patent was rejected because Osram was not using garnet-based phosphors.) However, the way in which successive patents gradually extend the scope of the claims means that even this aspect is not clear-cut.

Fixture manufacturers

In terms of patents, the situation has parallels in another case involving the way in which LEDs are used in luminaires or fixtures. Color Kinetics (CK), a Boston-based lighting manufacturer, has a large number of patents (and even more patent applications) which it is attempting to enforce through licensing agreements. It is being opposed by other manufacturers who set up the LED Alliance in October 2004, claiming that many of CK's patents are invalid (see *LEDs Magazine* April 2005 "Patent protagonists head to court").

Others have gone further in accusing the US patent system of malfunctioning. The following quote was carried in the January 2005 issue of *Lighting & Sound International* magazine: "The US Patent and Trademark Office basically relies on two sources to check novelty – its own search of prior patents and the inventor's disclosure of relevant prior art. It does not carry out any search of existing products or technology itself."

A glance at the US white light LED patents suggests that even this is an overgenerous interpretation, but one conclusion resulting from the lack of clarity is the same: patents issues can be won not on merit, but on who has the most money.

Phosphors

A key difference between some of the patents is the choice of phosphor, or "down-converting" material. The major phosphors are:

- Yttrium aluminum garnet (YAG) doped with cerium, excited at about 460 nm and with a broad emission peak centre at 550 nm.
- Terbium aluminum garnet (TAG), licensed by Osram to several manufacturers.
- Sulphide phosphors such as strontium thiogallate doped with europium, excited at 460 nm and emitting in the green (550 nm), or strontium sulphide doped with europium and emitting in the red.
- Silicate-based structures such as those patented by Toyoda Gosei and Tridonic, and also by Intematix.
- Organic phosphors or dyes. It is not clear if a "fluorescent dye" would cover the first two categories.
- Nanoparticle phosphors, which are the subject of other patents but are not described in the patents listed above.

Multiple patent applications

A comparable situation is developing in Europe, perhaps slightly belatedly. A search of published European patents shows that from mid-2004 to mid-2005 the "big five" between them published over 60 patent applications on blue and white LEDs (and had presumably filed even more).

It is often hard to identify novelty in these applications, and some are clearly just attempts to extend existing US patents to Europe.

However, the number and complexity of these patent applications means that any attempt to file objections on, say, grounds of prior art, is a major problem for small companies, which will find it impossible to invest the resources needed to carry out careful assessments and prepare their case. Without the confidence that only the truly novel will be identified by patent officers, many small businesses could see their activities threatened.

Threats of legal action impinge not only on manufacturers, but also on distributors. Licensing a technology or design from one major manufacturer does not, by the apparent terms of the cross-licensing agreements, prevent attack by another. It is not only any small manufacturer of white LEDs that is affected, but also those using the LEDs in lamps and luminaires.

From the perspective of any company outside the big five the position is almost impossible. It is not at all clear where they should apply to for licenses, or indeed what requires a license. None of the legal cases that have been resolved so far have clarified the issues as they have been almost entirely limited to deciding whether a patent has been infringed, and not whether the patent *per se* is valid. The fact that a number of licensing agreements have been reached between the big five and other companies does not in itself answer the questions, and may simply reflect legal muscle and aggression. Even worse, a licensing agreement with one company does not necessarily offer protection from one of the others.

Small companies suffer

The effect is to stifle innovation and decelerate development of the market, including in particular the involvement of small and medium enterprises (SMEs). If, for example, a small company can be confident that the basic idea of a blue LED plus complementary phosphors is not subject to a valid patent, then it can look at novel implementations of the concept to avoid infringing more specific patents (although even here it requires a major stretch of the imagination to think that some of the patents involve any innovation at all).

Alternatively, if the small company knows which patents really are valid, it can apply for a license. If the patents cover only the use of specific phosphors then there are a number of companies offering commercial phosphors which they claim are patent-free. If the basic principle is not covered, then anyone is free to use these phosphors to manufacture white LEDs.

What can be done? The example of the LED fixtures industry may provide a model, where an "LED Alliance" may provide sufficient resources to be able to match the resources of the larger companies, and so allow the courts to clarify the position. Indeed, there is some hope that the courts are already beginning to become involved not only in the question of infringement of patents but also in their validity. Two cases are likely to be resolved in the coming months, Citizen Electric Company versus Osram GmbH in the District of Columbia District Court (and in Düsseldorf), and Osram Semiconductor versus Dominant at the US International Trade Commission.

In this latter case the original ruling was broadly in favor of Dominant (see *LEDs Magazine* article "Dominant cleared of infringing Osram Opto's patents"), and stated that a key patent was invalid because of the lack of precision in defining particle sizes. Osram appealed, and the Commission has issued a reply to this appeal in August 2005, in which they contradict the original ruling, saying that the definition of average particle size is sufficiently precise, although it must be taken as the volume average. However, they also state that Dominant does not infringe the original Osram patent because this was explicitly based on a uniform layer of phosphor, which Dominant does not use. Apparently other issues remain to be settled.

Presumably this detailed discussion of definitions is part and parcel of a patent lawyer's life (and charges), and not something that will appeal to the CEO of a typical SME. Legally, it is probably much easier to discuss definitions than to address the question of, for example, the prior art involved in using phosphor particles of very small diameter.

However, the narrow focus confirms that the basic principle of color down-conversion is not covered by any valid patent, and that what is at issue is the precise implementation. More specifically, in answer to the basic question of who, if anyone, has a valid patent for a white light source involving a blue LED and a standard YAG:Ce phosphor, it may well be that the answer is no-one.

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Patents & Licensing: Blue and white LEDs
www.ledsmagazine.com/articles/features/1/8/21/1

IP issues influence fixture makers and LED suppliers

Jed Dorsheimer of Adams Harkness tells *LEDs Magazine* how the resolution of the Color Kinetics vs. Super Vision patent dispute could have a positive effect on the industry.

As an analyst with Adams Harkness, Jed Dorsheimer's knowledge of compound semiconductors and device physics has helped him focus on exciting growth opportunities in the display and solid-state lighting markets, as well as a variety of broader enabling technologies.

Here, he talks to *LEDs Magazine* about the CK vs. SV patent dispute and how the emergence of new phosphor technologies could force LED makers to reassess their approach to protecting their IP and markets.

"Now there has been a ruling, companies waiting on the sidelines can use this as the basis to make a decision on how to participate in the market."

JED DORSHEIMER

What was your view of the patent judgment in favor of CK?
I felt it was a validation of their technology, after many people argued that their patents would not hold up in court. The ruling sends a message to the industry in general that CK's patents are valid.

What are SV's prospects for an appeal?
As a result of this ruling, the hill that SV was climbing has become larger and steeper. It appears to me that every time a court rules in favor of someone's patents, this makes it more difficult to overturn this decision in future. Even so, SV thinks that mistakes have been made, and is taking its case to the patents appeal court.

How will this affect companies that are not CK licensees?
I see this as a positive step for the industry in general. Now there has been a ruling, companies waiting on the sidelines can use this as the basis to make a decision on how to participate in the market. Rather than spending money on court battles, the industry can start enabling the technology and focusing on making improvements.

Is this a bad result for the companies that will not be able to participate either through choice or because they lack the necessary licensing funds?
I don't agree this will be a problem – there are several legal precedents in other markets, for example the PC software market. Despite Microsoft's predominance in this market, other competitors continue to enter. In this case, there are technologies other than pulse-width modulation (PWM) that could be used for control and color-changing. The ruling may serve to focus people's minds on developing new technologies. Equally importantly, the market size and potential can support many other players in the market.

What is the current state of patent disputes between the larger LED suppliers and their low-cost competitors in countries such as Taiwan?
In recent years we have seen Taiwanese companies able to penetrate the keypad portion of the handset. Blue surface-mount LEDs used to backlight keypads have suffered severe price erosion as a result of strong competition among Taiwanese (and other) suppliers.

It seems apparent that IP does not carry the same weight in this market, which has the lowest value proposition for the larger manufacturers. This mainly hurt Cree, which was supplying chips for this market. However, Cree chose not to defend its IP against the Taiwanese companies, despite making several bold statements to the industry.

Instead, we did see Nichia unsuccessfully challenge Epistar at the chip level, in a dispute that concerned the use of NiAu contacts.

When did the focus shift to white LEDs?
Having failed in its dispute with Epistar, Nichia launched a patent campaign targeting white LED technology infringement, and Osram also made a lot of noise in that area. Osram also licensed its TAG-based phosphor white LED technology to a number of suppliers in Taiwan, namely Harvatek, Lite-On and Everlight, as well as Rohm, Samsung and Vishay.

What this says to me is that the two players that have the means and willingness to defend their IP in this area appear to be Nichia and Osram. These companies are attempting to maintain IP barriers that will prevent penetration from lower-cost competitors in key high-end markets, such as LCD-screen backlighting using white LEDs. Both companies will draw lines in the sand with respect to such products as Taiwanese companies increase the performance of their products.

Will it be possible to maintain these barriers?
Although Nichia and Osram have strong patents covering white LED technology, other companies have technology outside these patents.

"Will Nichia now return to defending its IP at the chip level, if it can't maintain the IP boundaries at the phosphor/white LED level?"

For example, Intematix manufactures silicate-based phosphors which are claimed to offer similar performance to YAG-based phosphors, and which have already been licensed by at least four packaging companies. Products using this and other technology could soon start to challenge the performance of white LEDs manufactured by the leading players. This presents an interesting dynamic – will Nichia now return to defending its IP at the chip level, if it can't maintain the IP boundaries at the phosphor/white LED level?

What will this mean for chip suppliers that are not considered "IP friendly"?
This will present a difficult issue for the low-cost suppliers, many of which produce blue LED chips that probably infringe on Nichia's IP. Cross-licensing and strategic relationships will be key for these companies to penetrate the high value-added markets which Nichia will want to protect.

Have any of these strategic agreements been put in place?
Nichia has an agreement with (and has invested in) a Taiwanese company, Opto Tech, which manufactures chips under license from Nichia. Both Osram and Intematix have licensed their white LED phosphor technology to different Taiwanese packagers. Both Cree and Toyoda Gosei have manufacturing relationships with companies in Taiwan, but nothing that could be described as strategic technology licensing. However, it's likely that the major players are in discussion with their Taiwanese counterparts.

There have been a couple of recent mergers in Taiwan – will that trend continue?
Yes, I think so. Taiwanese manufacturers significantly increased their capacity, particularly once they started to penetrate the keypad backlighting market in handsets. As supply started to saturate and some OEMs reduced the number of LEDs used per handset, there was a slowdown in demand. Although recent demand has picked up somewhat due to ASP erosion, the level of economic profitability has dropped. Consolidation is a way for companies to leverage their R&D efforts, as well as invested capital.

Mergers make most sense at the chip level, since capacity has been mostly increased by the acquisition of multiple MOCVD reactors [machines for growing LED wafers]. In the recent merger between Epistar and UEC, the former has core competency in InGaN-based chips while UEC is a leading supplier of AlGaInP chips. Epistar [as the merged company will be known] has expressed an interest in producing a full RGB solution for backlight unit applications for 7-inch and above FPDs. This will be assisted by Epistar's close relationships with several packagers in Taiwan.

How would you summarize the IP situation in the SSL industry?
In a state of flux – which I believe is a positive sign, as it means the industry is growing. If we were not seeing any activity on the IP side of things, this would cause concern, as it would not represent a large enough industry to attract new entrants. Therefore, the activity that we are seeing is normal in my opinion and I liken it to the more mature semiconductor and semiconductor capital equipment markets.

Further, I believe the size and scope of this market is large enough for many companies to prosper, both large and small. Just look at the size of the markets we are talking about: combining the display markets with the lighting markets is well over a hundred billion dollars annually – that's huge. So, when we sometimes focus on the minutiae it's healthy to step back and try and see the forest through the trees – these activities are normal and healthy for LED technologies and the companies involved.

About the interviewee

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On our website:
LEDs provoke Bright Ideas among investors
www.ledsmagazine.com/articles/features/1/12/5/1

Dimming method affects chromaticity of white LEDs

A study of dimming methods indicates that the lowest chromaticity shift among high-power white LEDs is observed for phosphor-converted LEDs dimmed using pulse-width modulation.

At the recent Solid State Lighting conference (see p29), Marc Dyble from the Lighting Research Center at Rensselaer Polytechnic Institute presented a paper on the extent to which the chromaticity of different high-power white LED systems is affected by the use of different dimming methods.

In architectural lighting applications, dimming is an essential functional and aesthetic requirement for many types of spaces. The growing interest in white LEDs for general lighting has led to more flexible means of dimming control for these devices. However, maintaining a relatively constant white color while dimming LED systems is a challenge. In general, a noticeable chromaticity shift during dimming is not desirable.

Two methods of dimming are available for white high-power LEDs: continuous current reduction and pulse-width modulation (PWM). These techniques can be applied to either mixed-color RGB (red, green and blue) LEDs or phosphor-converted (PC) white LEDs.

Continuous current reduction involves a decrease in current supplied to the LED, which proportionally lowers the light output level. PWM involves rapid on-off cycling of the LED at a frequency high enough to eliminate any perception of flickering.

However, little data has been recorded showing the chromaticity shifts resulting from these methods. The objective of this study was to evaluate the chromaticity shift of high-power RGB and phosphor-converted white LEDs under these two dimming schemes.

Experimental set-up

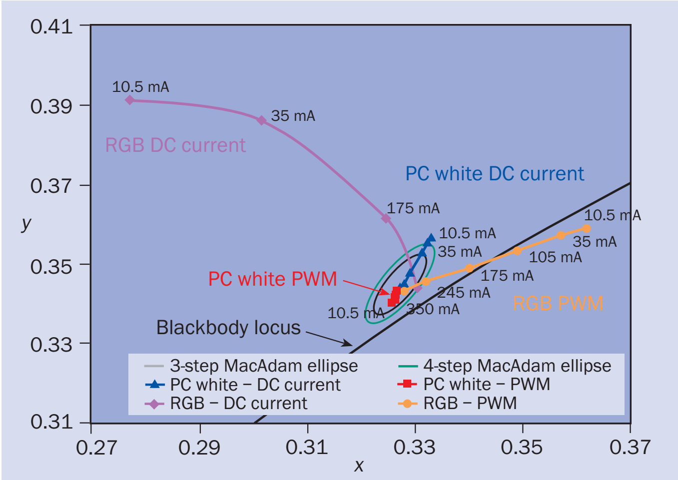
RGB and phosphor-converted white LEDs were mounted onto a 6-inch diameter round white-painted aluminum heat sink with a thickness of 0.25 inch.

The PC white LED system consisted of nine PC white LEDs, while the mixed-color LED system comprised three each of red, green and blue LEDs, and the mounting positions of the LEDs were alternated such that no two similar colors were adjacent to one another.

Each of the systems was operated separately at several different dimming levels using the two dimming methods of continuous current reduction and PWM. Light output and spectral data were recorded for each LED system inside a 6 ft diameter integrating sphere. The light output level was adjusted in steps between 100% and 3% during the study.

Chromaticity results

Figure 1 shows the results for each system at different dimming levels under each method. The white color point for each condition is plotted on a CIE 1931 chromaticity diagram.



Chromaticity shifts of phosphor-converted and RGB mixed-color LED systems under two types of dimming: continuous current reduction (DC) and pulse-width modulation.

Overall, using either dimming method, the chromaticity shift for the PC white LED system was less than that of the mixed-color RGB LED system. Additionally, each method caused the chromaticity to shift in different directions.

Both dimming schemes provide small chromaticity shifts using the PC white LED system, with the PWM performing better than the continuous current dimming scheme.

The RGB mixed-color system suffered large chromaticity shifts, regardless of the dimming scheme used. An active optical feedback scheme could be implemented for the mixed-color LED system to control the chromaticity shift and to confine it within a four-step MacAdam ellipse, the criterion for unnoticeable color variation.

The authors correctly point out that the results cannot be extrapolated directly to other packages, since the behavior may be directly related to and determined by the package used, although the study does begin to indicate the importance of dimming schemes on white LED lighting schemes.

Further reading

M Dyble, N Narendran, A Bierman and T Klein 2005 Impact of dimming white LEDs: Chromaticity shifts due to different dimming methods *Fifth International Conference on Solid State Lighting* Proceedings of SPIE 5941 (in press; www.spie.org). See www.lrc.rpi.edu/programs/solidstate/pdf/dyble-SPIE2005.pdf.

LEDs MAGAZINE

Accurate modeling of LED colors: a scientific approach

LED light sources are being used more frequently in large-scale applications, but planning them can be hampered by poor color rendering on computer screens. **Ian Ashdown** of byHeart Consultants Limited discusses methods for improving on-screen color accuracy.

As architects embrace multicolor LED-based luminaires for architectural and entertainment applications, we as lighting designers are faced with a problem. We can offer computer-generated renderings to our clients, but it is often difficult to produce realistic colors.

One of the problems is that lighting design programs allow us to specify the color of light sources. This is great, except that we need to know what colors to use for modeling real-world LEDs.

Our first attempt is usually to do this:

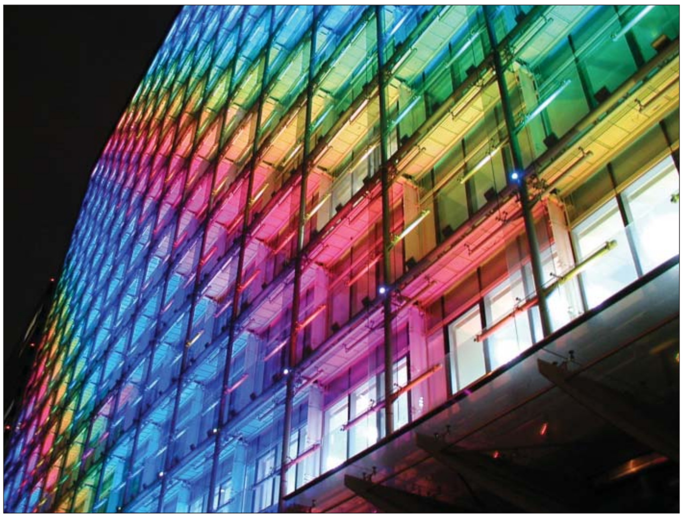
- Red: (1.00, 0.00, 0.00)
- Green: (0.00, 1.00, 0.00)
- Blue: (0.00, 0.00, 1.00).

Here, we have assumed that "red is red" and so forth. However, we quickly learn that the "green" is too yellowish, and that in general the rendered colors do not appear very realistic when compared with color photographs of finished solid-state lighting installations. If the renderings are meant to show the client what the project will look like, this is not an auspicious beginning.

The second attempt – often done in a panic as deadlines loom – is to determine approximate color values through trial and error. For example, we might take a color photograph and attempt to match the red, green and blue colors with those displayed on our video displays.

This is a risky approach, as in general we do not know whether the LED luminaires were generating single colors, and we do not know the colors of the surfaces they were illuminating. Still, it is better than the first attempt.

Our third attempt... well, let's take the scientific approach and do it properly.



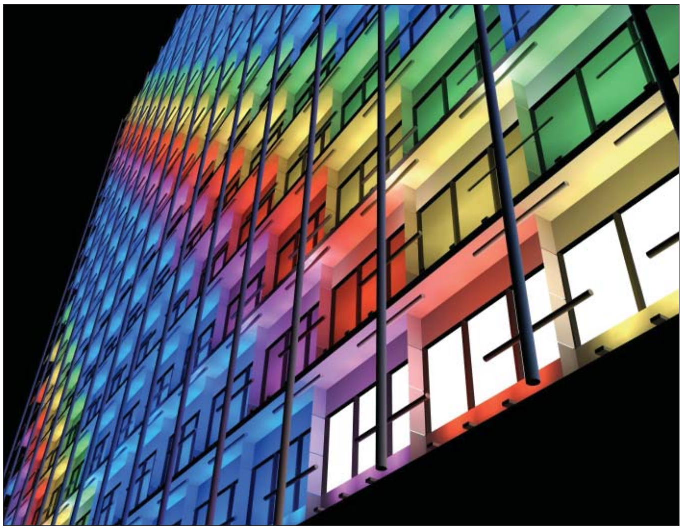


Photo of the Kuo Hua Commercial Insurance Building in Taipei, Taiwan (top), and a design rendering of the same building (bottom). (Photo courtesy of TIR Systems Ltd.)

Plotting colors

We already know that we can generate most colors by combining red, green and blue light. This is after all how both multicolor LED luminaires and color video displays work. Our problem is that the CRT display phosphors (and their equivalent LCD display color filters) do not produce the same colors as do red, green and blue LEDs.

We can visualize this problem by plotting the colors on the CIE 1931 *xy* chromaticity diagram. Most CRT displays use ITU-R BT.709 phosphors with the *xy* chromaticity coordinates shown in the table "ITU-R BT.709 phosphor properties". (LCD displays use color filters rather than phosphors, but they have similar chromaticity coordinates.)

Plotting these colors on the CIE chromaticity diagram gives a triangle that defines the color gamut for the display (figure 1). By mixing various amounts of red, green and blue, we can generate any color contained within this triangle. What we cannot do is generate colors that lie outside the color gamut of the CRT or LCD display.

Now, what about red, green and blue LEDs? Well, one problem is that their chromaticity coordinates typically lie outside of the color gamut of CRT and LCD displays. For example, a Lumileds Luxeon

ITU-R BT.709 phosphor properties

Phosphor	x	y
Red	0.640	0.330
Green	0.300	0.600
Blue	0.150	0.060

Data refers to xy chromaticity co-ordinates of ITU-R BT.709 phosphors which are used in most CRT displays [1].

RGB values for Luxeon LEDs

LED color	Dominant wavelength λ_D (nm)	RGB values
Royal blue	455	0.05, 0.00, 0.95
Blue	470	0.00, 0.11, 0.89
Cyan	505	0.00, 0.63, 0.37
Green	530	0.00, 0.77, 0.23
Amber	590	0.70, 0.30, 0.00
Red-orange	615	0.97, 0.00, 0.03
Red	625	0.92, 0.00, 0.08

green LED may have chromaticity coordinates $x = 0.288$ and $y = 0.710$.

We can however approximate this color by drawing a line from the white point through the LED color to the spectral locus (the horseshoe-shaped curve). The color on the spectral locus represents a fully saturated color that has a specific wavelength (measured in nanometers) of the visible spectrum.

As we move closer and closer to the white point along the line, the corresponding color has approximately the same hue, but it becomes more and more desaturated as we add increasing amounts of white light.

The specific wavelength is called the dominant wavelength λ_D of the LED, and it is the metric that LED manufacturers use to bin their color LEDs. Lumileds, for example, bins its blue and green LEDs at 10 nm intervals.

While we cannot reproduce the green LED color on a CRT or LCD display, we can generate a desaturated color with the same hue. Referring once again to our line, this is the line's intersection with the display's color gamut triangle.

One of the advantages of the CIE 1931 *xy* chromaticity diagram is that it is linear. For example, the relative distance of the desaturated green LED color from the blue and green phosphor colors represents the ratio of blue and green for the corresponding RGB triplet we need to describe the light source color. In the example shown in figure 1, the RGB values are: (0.0, 0.7, 0.3).

Our problem therefore has a simple geometric solution. If we know the average dominant wavelengths of the LEDs in a multicolor LED-based luminaire, we can determine the equivalent RGB values needed to model the LED colors in our lighting design program.

All we need are the chromaticity coordinates of the white point...

White points

As lighting designers, we know that fluorescent lamps have different color temperatures, and yet we refer to them as "white light" sources. Not surprisingly, the same concept and terminology applies to CRT and LCD displays. When a display generates "white" (which is its white point), the color has a specific color temperature.

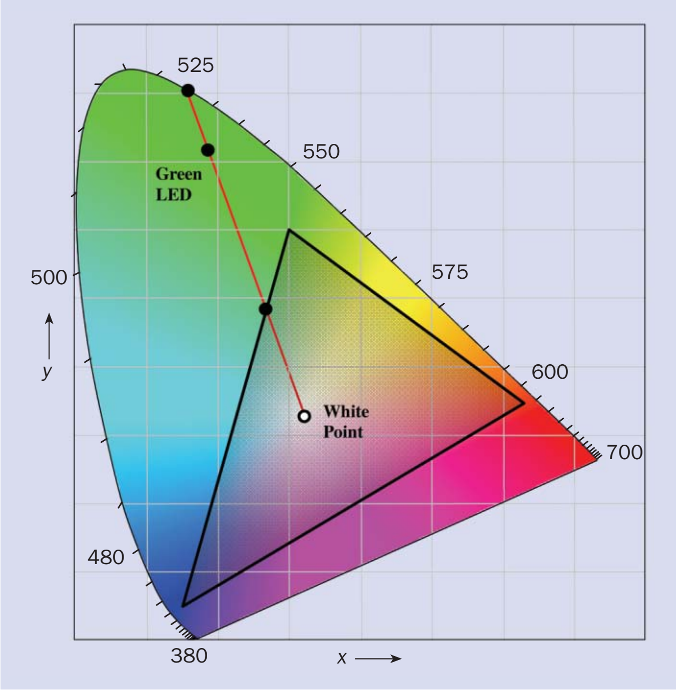


Fig. 1. Video display color gamut on the CIE *xy* chromaticity diagram.

For many years, CRT displays had a color temperature of 9300 K – a "white" that we would find intolerably blue as a fluorescent light source. The reason is historical; blue phosphors were more efficient than red and green phosphors, and so CRT display manufacturers opted for a high color temperature in order to maximize the display luminance.

The situation has changed since the introduction of LCD displays, which typically have a color temperature of 6500 K (which is close to daylight on a clear day). Most modern CRT displays now provide the option of either of these settings for their white point.

So we apparently have a choice of chromaticity coordinates for our white point:

- 6500 K (0.313, 0.329)
- 9300 K (0.283, 0.297).

Color constancy

Why "apparently?" Well, there is one more complication. Most lighting design programs implicitly assume that the color temperature of "white" light sources (including daylight) is 6500 K. When we view the computer renderings on a 9300 K CRT display, we are viewing what should be 6500 K white as a much bluer 9300 K white. All other displayed colors are similarly affected – it is as if we were viewing the scene through a light blue color filter.

This however is not a problem, as color constancy comes to our rescue. We mentally subtract the overall bluish color cast and see the rendering in what appear to be its "true" colors.

It therefore makes sense to assume 6500 K as our white point, regardless of the actual display color temperature. This will allow us to view the renderings without being concerned about the display properties.

With this, we can determine the equivalent RGB light source values for typical LED dominant wavelengths. The calculations are straightforward but somewhat tedious. However, we can choose representative Lumileds Luxeon products by noting that other manufacturers' LEDs will have similar dominant wavelengths. Performing the calculations for these products, we obtain equivalent RGB values as shown in the table "RGB values for Luxeon LEDs".

Digital cameras

We are almost done. Although we have taken the scientific approach to modeling RGB colors, there may still be visual discrepancies between our renderings and digital photographs of the finished installation. Why is this? There may be many reasons, but here are some key points to keep in mind:

- The spectral (color) responsivity of digital cameras usually differs from that of the human eye.
- The camera may automatically adjust its white point according to the scene content, and it may not assume a 6500 K illuminant.
- The display device must be properly calibrated using color management techniques and hardware for side-by-side comparisons.
- The illuminated surfaces in the digital photograph may have different colors than those assumed for the computer model.

These are all color management issues, which require entire books to properly explain [2]. It is possible to adjust CRT or LCD displays such that colors within their color gamuts will appear the same on each device. However, it is generally not possible to calibrate digital cameras except when used under carefully controlled studio lighting conditions.

Lighting design and color

Multicolor LED-based luminaires have brought vibrant and dynamic colors to our lighting designs. By taking a scientific approach to modeling LED colors, we can minimize the differences between what our computer renderings show and what the client will see with the finished project. It may not be precisely "what you see is what you get," but we can come as close as today's display technologies allow.

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References

1 ITU-R Recommendation BT.709, *Basic Parameter Values for the HDTV Standard for the Studio and for International Programme Exchange* (1990).

2 See for example B Fraser, C Murphy and F Bunting 2005 *Color Management, Second Edition* (Berkeley, CA: Peachpit Press).

Acknowledgment

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Microcontroller-based LED drivers: topologies and trade-offs

Drivers based around microcontrollers can be simple to design and offer a number of advantages for controlling high-intensity LEDs. However, some limitations remain, as **Pedro Pachuca** and **Rod Borras** of Freescale Semiconductor discuss.

A number of different topologies can be achieved with a microcontroller at the heart of an LED driver system. In this article, the topology trade-offs are discussed in detail, with an emphasis on the major features and limitations: communication, voltage and current capabilities, dimming techniques and switching speed.

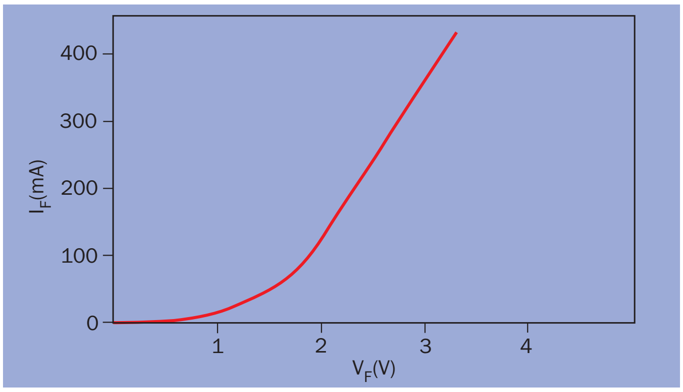

Fig. 1. LED voltage–current relationship.

Driving high-intensity LEDs

High-intensity LEDs (HI-LEDs) are different from standard LEDs based on their power input: traditional LEDs are generally limited to less than 50 mW, while HI-LEDs operate at 1–5 W.

Figure 1 represents a typical voltage–current relationship in a HI-LED. Almost no forward current (I_F) will flow through the HI-LED until the forward voltage (V_F) exceeds the internal barrier voltage. If the V_F is increased further, the curve follows the shape of a knee and suddenly rises at a rapid linear rate.

The light output of an LED is proportional to the forward current, so if this I_F is not controlled properly, it can result in an unacceptable variation in light output. Also, exceeding the manufacturer's maximum I_F specification can seriously reduce the LED's useful life.

HI- LEDs should be controlled by electronic drivers whose primary function is to generate a source of constant current. These circuits can provide luminosity control using the techniques described hereafter, and in some cases compensate for temperature changes as well.

HI-LED manufacturers suggest dimming the LED by pulsing it at its constant nominal current to ensure that the system will provide color uniformity.

The challenge in designing a HI-LED driver is to create a well controlled, programmable, constant current source, with high efficiency.

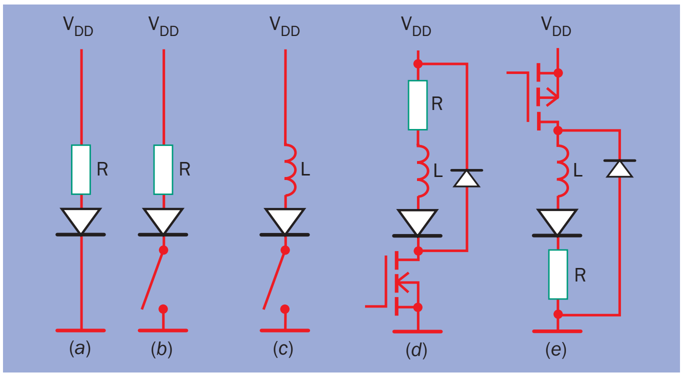

Fig. 2. LED driver topologies.

Using a series resistor (linear approach)

The simplest way of setting a current is by adding a series resistor, (figure 2a). The advantages are a low cost, simple implementation, and no generated noise due to switching. Unfortunately, this topology has two major drawbacks: reduced system efficiency due to significant losses in the resistor, and the inability to change the luminosity. Also, this solution requires a constant voltage source to achieve a constant current. For instance, if we assume that V_{DD} is 5 V, and that the LED's V_F is 3 V, then to produce a constant current of 350 mA, you will need: $R = V/I$, or in this case, $R = (5\ V–3\ V)/350\ mA = 5.7\ \Omega$.

We can see that with these values, R will dissipate $R \times I^2$ or 0.7 W (almost as much as the LED), so the overall efficiency will inevitably be less than 50%.

This approach assumes a constant V_{DD} and a constant V_F. In fact V_F varies with temperature, and so will the current. Using a higher V_{DD} will minimize the overall current variation due to the V_F, but will also create significant losses in the resistor, further reducing the efficiency.

Once we have created a constant current through the LED, we then need to find a way of setting different luminosities. Given that these LEDs need always to be driven at their nominal current, we can achieve luminosity control by turning that current source on and off with a programmable duty cycle. This will require a switch (figure 2b).

By adding a transistor and/or an op-amp, the current can accurately be programmed to 350 mA. Unfortunately, the overall efficiency and R power losses remain the same.

Using a low-side switch

Figure 2c shows the low-side switch (switched-mode) concept. We can program the current flowing through the LED by allowing current to build-up in inductor L when the switch is on, and ramp down when the switch is off (figure 3). As with any inductive load, we need to provide a path for the current when the switch is open. This is achieved via the freewheeling diode represented in figure 2d (p24). We have replaced the switch with an N-channel MOSFET, and also added resistor R to measure the current through the LED.

The switch will turn on when the current decays to the lower current threshold (e.g. 300 mA) and will turn off when the current builds up to the upper threshold (e.g. 400 mA).

This example has the switch on the "low-side" (hence the name), and makes for a very easy implementation. All that is needed to turn on the FET is 5 V on its gate. This could be provided directly from one of the microcontroller outputs. Furthermore, this topology no longer needs a constant V_{DD} voltage and will regulate the current, even for fluctuating input voltages.

The current-sensing resistor R has to be in the "high-side" portion of the circuit. If it were connected to the source of the MOSFET, it would only see the LED current while the switch was on, and could not be used to set a secondary threshold (figure 3).

This topology, which looks like the front-end of a boost converter, has the advantage of using an N-channel, low cost FET, but requires a differential voltage measurement across R to extract the current through the LED.

Note that the switch actually provides two functions: first, it allows for a programmable current to be set in the inductor, and second, it allows for luminosity dimming.

Using a high-side switch

This is the same circuit as before, except that the load and the transistor have traded places. The switch is now in the "high-side" (figure 2e p24). We have also changed the FET from N-channel to P-channel. An N-channel FET would require $V_{GS} > 5$ V to turn on fully: in this topology, the N-channel's source voltage will vary, and will often be above 3 V, so we would need at least 8 V on its gate. This requires a gate-drive circuit, like a charge-pump, and makes the overall circuit slightly more complex. It is simpler to just have a P-channel FET, and provide a V_{GS} of –5 V, once again directly from a microcontroller output. This topology is similar to the front end of a buck converter. The main advantage here is that the current measurement is done directly across R, and therefore does not have to be a differential measurement.

Dimming techniques

There are many techniques for dimming LEDs, some of which may be patented. Below is a brief description of some of them. In all cases, control is achieved by turning the LED fully on (at its nominal current) and off at very high speed (to avoid flickering), and the average luminosity is proportional to the percentage of time the LED is on.

- **Pulse-width modulation (PWM):** this technique uses a fixed frequency of period T (figure 4). The dimming is achieved by varying the pulse width. Figure 4 shows three different luminosity levels, with duty cycles of 6%, 50%, and 94%.
- **Frequency modulation:** this technique, published by Artistic Licence, uses the concept of a fixed-width control pulse. As described in figure 5, pulse A is always of the same duration, and the luminosity is controlled by how often pulse A repeats itself.
- **Bit-angle modulation:** this new technique, invented by Artistic Licence, is based on a binary pulse train that contains the intensity value. Every bit in the pulse train is stretched proportionally to its sig-

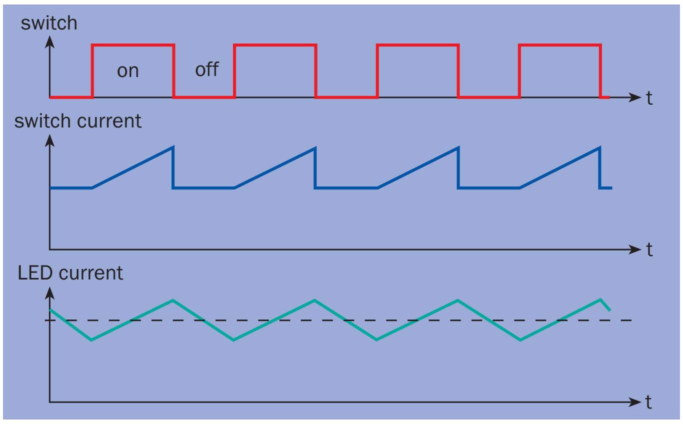

Fig. 3. LED and switch currents.

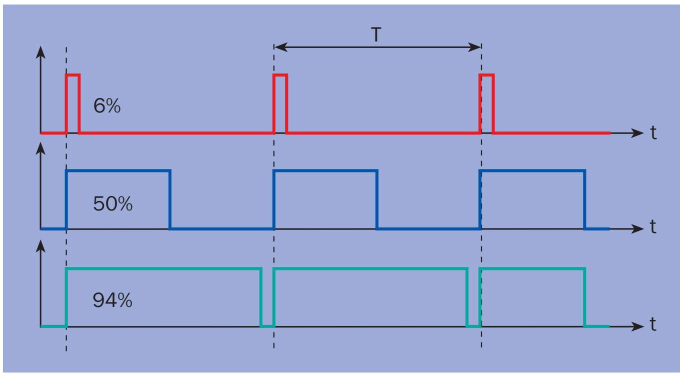

Fig. 4. Pulse-width modulation.

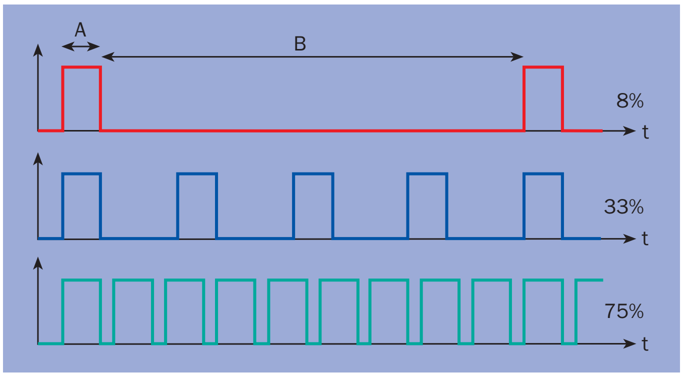

Fig. 5. Frequency modulation.

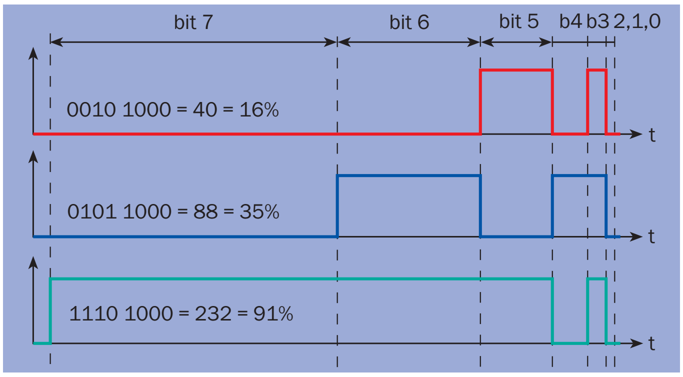

Fig. 6. Bit-angle modulation.

nificance. If the least significant bit b0 has a duration of 1, then bit b1 has a duration of 2, bits b2 through b7 have durations of 4, 8, 16, 32, 64 and 128, respectively (figure 6 p25).

Communication protocols

- **DMX512:** a standard published by the US Institute of Theatre Technology. The protocol, initially used to control lighting dimmers, has been extended to control lamp movement, slider projectors and many other lighting accessories. DMX512 runs over an EIA-485 standard. Data transmission is based on 8-bit asynchronous serial communication, 1 start bit, 2 stop bits and no parity; it allows 256 dimming levels.
- **DALI (digital addressable lighting interface):** a standard that has been developed for communication with electronic ballasts. It is included as an appendix to ECG standard IEC 929. DALI is designed for standard components and for simple wiring, which means low costs.

  Applications include dimming lights; pre-setting values for different lighting environments; properly adjusting light settings depending on the direction of daylight; and energy savings.

  DALI is based on the master–slave principle: the user operates the system through the controller (master); the controller sends messages to all the ballasts (slaves) containing an address and a command. The address determines whether the ballast should listen. Each ballast is digitally addressed and therefore is insensitive to electromagnetic noise (an improvement over the analog 1–10 V dimmer switch system).
- **ZigBee:** a communication protocol from the combination of Home RF lite and the IEEE 802.15.4 specification. ZigBee operates in the 2.4 GHz and 868/915 MHz ISM bands, and lighting applications are one of its primary markets owing to its capability to offer low power consumption at low cost. ZigBee offers network capabilities useful in lighting systems, as well as the advantages of wireless control.

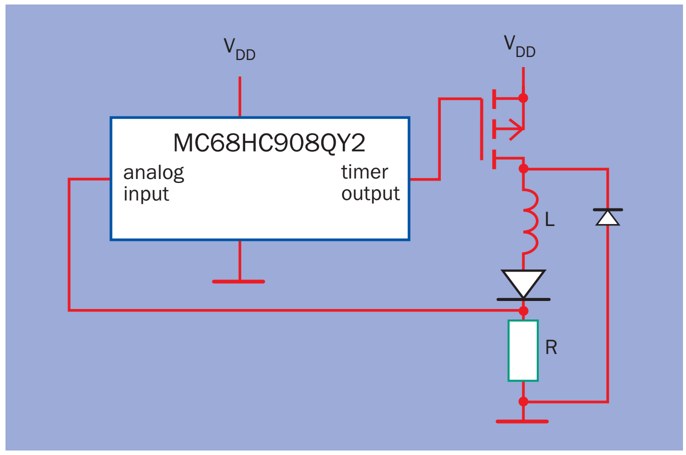

Fig. 7. Microcontroller-based LED driver.

assumptions
1. V_{DD} = 5 V, V_F = 3 V
2. I_F = 350 mA, with lower/upper thresholds at 300 mA/400 mA

resistor R
max power losses: 1/4 W, so R $Imax^2$ < 0.25 W
Imax = 400 mA, so R < 1.56 Ω
R set at 1 Ω, for a max voltage drop of 400 mV

inductor L
max 10% error (40 mA)
with 15 µs uncertainty, and V = L di/dt
L > (5 V – 3 V) * 15 µs/40 mA, so L > 750 µH

Fig. 8. Basic design considerations.

Limitations using a microcontroller

- **Voltages and currents:** If V_{DD} is the supply to both the LED and the microcontroller, then there is only enough voltage to drive one LED. The simple topologies we have discussed do not allow for the LED voltage to be higher than V_{DD} (figures 2 and 7). For more LEDs in series, with the benefit of all being at the same current, V_{DD} has to be higher and now requires a power supply for the microcontroller.
- **Physical interfaces:** the microcontroller only provides simple synchronous or asynchronous communication. It would need additional hardware and software to implement DALI, DMX, LIN etc.
- **Switching speed:** the key parameter in this application is switching speed. The slower the switching speed the larger the inductor, and therefore its cost. Most microcontrollers can accomplish an A/D conversion in about 15 µs. Add a few instructions to compare the read value to internal thresholds, and we are now talking 30–40 µs for the full analysis for each ON or OFF cycle, with an uncertainty of about 15 µs. This error dictates the minimum inductor value (figure 8). Another approach is to set arbitrary ON and OFF durations, and then readjust these after the fact, to try to accommodate the two current thresholds. This indirect method allows for a smaller, lower cost inductor, but is less accurate.
- **Dimming and modulation:** at 100% luminosity, there is no need to modulate the transistor. At the other extreme, for the lowest luminosity level, e.g. 1%, it will be necessary to have the transistor on for 1% of the time. Given the fact that dimming must be done at 100 Hz or higher to avoid flickering, the PWM clock must be 10 kHz or higher. But the eye can detect tiny changes in the low luminosity range, and therefore 100 steps are not enough. If 4000 steps were needed (12-bit resolution), the PWM clock would have to be upwards of 400 kHz, which is almost impossible for a simple microcontroller.

The future

We have seen how simple it is to design a microcontroller-based HI-LED driver. The three main limitations encountered were processing speed and the impact on inductor size and dimming resolution; communication capability with industry standards; and drive capability for multiple outputs and/or LED strings. We will address solutions for all these limitations in a future article.

About the authors

Pedro Pachuca is 8-bit microcontroller vertical market development engineer and Rod Borras is analog senior market development engineer with Freescale Semiconductor, Austin, Texas.

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Cyberlux matches attributes of LED lighting to market needs

Emergency lighting and defense-related products have set the stage for US solid-state lighting specialist Cyberlux to begin to penetrate the general lighting market. *LEDs Magazine* spoke with **Mark Schmidt**, president and COO of Cyberlux, about the company's plans.

Fig. 1. The RelyOn portable and long-term emergency and work lighting product uses three 3 W XLamp LEDs supplied by Cree and has a maximum output of at least 250 lm.

Fig. 2. The Aeon Pro E is designed to illuminate kitchen and bathroom counters and has been measured by an independent test laboratory as having an efficacy of 55 lm/W.

On the same day in July that Cree announced a 3 W XLamp product with an output as high as 90 lm, the LED maker announced its first customer. Cyberlux, a solid-state lighting product company and manufacturer based just down the road from Cree in Research Triangle Park, NC, said that it had used Cree's new LED in its RelyOn portable and long-term emergency and work lighting product.

According to Mark Schmidt, the RelyOn product would not have been possible without the 3 W XLamp. "The product places a premium on long operating life, and also on very bright light," says Schmidt. "These two requirements made it important that we seek out a high-efficacy, high-lumen product, and Cree was head and shoulders above the competition. We found that the product was easy to work with, and was incorporated very easily into our manufacturing plans."

The RelyOn (see figure 1) is able to operate in spot- and flood-lighting mode, and can even be a desk lamp when sitting on end. "The value proposition given Cree's market pricing made it an affordable solution," says Schmidt. The LEDs represent about 25% of the total product cost, which makes the "dollars per lumen" metric for the LEDs a very important factor.

The RelyOn's output can be adjusted from 0 to 100% with infinite variability, for both spot and flood settings. This "fuel gauge" tells the user the percentage of battery life left, and the remaining battery life at the current level of output. With all three LEDs running at full power, the light operates for about 15 h, versus several hundred hours at the lowest output level.

Efficacy and lumen output

The value of 250 lm quoted for RelyOn is a minimum value, and the output can approach as high as 300 lm. For a power consumption of 9 W (three 3 W LEDs), the efficacy is somewhere around 33 lm/W. However, Schmidt expects this value to approach 40 lm/W over the next several months, thanks to continual improvement of the LED technology.

Another Cyberlux product, the Aeon Pro E (see figure 2), recently made headlines when independent test lab Independent Testing Laboratories Inc measured its efficacy as 55 lm/W. This value exceeds the 40 lm/W efficacy requirement for the new version of Title 24, the energy code set by the California Energy Commission. The Energy Star 4.0 standard also specifies 40 lm/W for residential lighting, although at this stage LEDs are not included in this rating.

The Aeon product line is designed for installation in closets, cabinet interiors and under cabinets to illuminate kitchen and bathroom counters, and as such represents an entirely different use of lighting, says Schmidt. The Aeon Pro E contains very-high-efficacy LEDs, while for RelyOn the emphasis is the balance between brightness and battery life. →

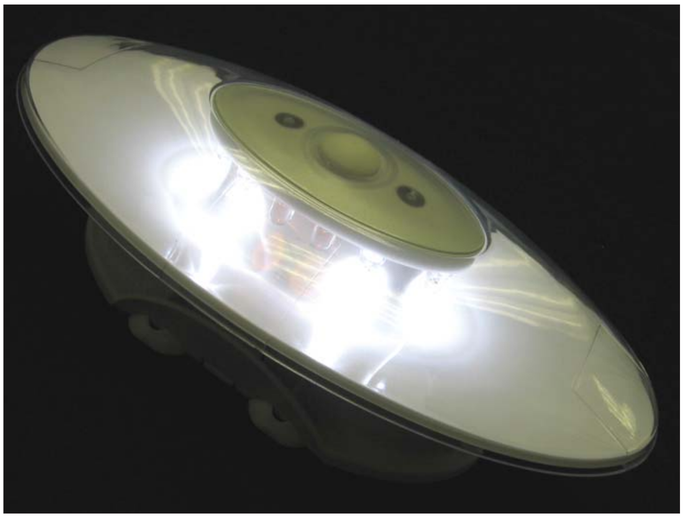

Fig. 3. The EverOn multipurpose emergency light provides more than 60 h of light using four AA batteries and is 90% more energy-efficient than conventional incandescent flashlights.

"We could drive the Cree 3 W to be very efficient, but the light output would be a lot less," says Schmidt. "Essentially, that's why we allow the user to control the light output of the RelyOn. The light can be very bright and last a shorter time [20 h], or it can last much longer when operating more efficiently at a lower output level." This functionality stems from the computer-level control that can be applied to solid-state lighting to allow the control of current, voltage and temperature.

Natural progression towards lighting

Cyberlux initially developed emergency lighting products, of which RelyOn is the latest manifestation, focusing on the energy efficiency and high light levels available from solid-state lighting. The EverOn multipurpose emergency light is the latest generation of the company's smaller, handheld emergency-lighting products. The EverOn (figure 3) provides more than 60 h of light using four AA batteries and is 90% more energy-efficient than conventional incandescent flashlights. The first generation of the EverOn product, the Home Safety Light, launched on TV shopping channel QVC last year and generated high demand, with sales exceeding $8000 per minute .

Energy efficiency, as well as ruggedness in the field, is also a key benefit of solid-state lighting for military and homeland-security applications, another target market for Cyberlux.

The company's general lighting products, including the Aeon line, targets the immediately available market space in closets, kitchens and bathrooms, for example. These products are geared more towards longer operating life, as opposed to devices like flashlights. In fact, the Aeon Pro product comes with a 15 year guarantee for the light source. "Title 24, which mandates energy efficiency for kitchen and bath lighting in California, is a great opportunity for us to get Aeon into a market that has very few alternatives in terms of energy efficiency," says Schmidt.

DreamWerks Design Studio, a manufacturer of custom kitchen cabinets, recently committed to using the Aeon Pro product as the standard lighting solution in all of its customized, high-end, Aero-Strata contemporary kitchen-cabinet line of products. "[We] had the opportunity to review the Cyberlux Aeon Pro under-cabinet lighting and were so impressed that we decided to standardize the Aeon Pro line," states Jon Brocksopp, president of DreamWerks Design Studio, LLC, of Racine, WI. "We build approximately 15 Aero-Strata kitchens a week in which we plan to use approximately 80 Aeon Pro lights, so for us to standardize on this product says a lot about the Aeon Pro solid-state lighting technology."

Teaming with Bruni

For a solid-state lighting manufacturer, one of the greatest challenges is gaining access to the very-large-lighting market. To this end, in late July Cyberlux announced a deal with Bruni Industria Mobili SRL, an Italian company which is one of the largest manufacturers of furnishing products, including lighting products and fixtures, for the European market. "The OEM route is the fastest way to market so that we can implement the technology in existing fixtures and lighting products," says Schmidt. "The partnership with Bruni is geared to providing access into existing channels."

Under the terms of the agreement, Bruni now has European marketing and distribution rights for Cyberlux products, and the two companies will work together to integrate Cyberlux technology into Bruni products. Schmidt explains that Bruni builds furnishings that often incorporate lighting and are used in commercial properties, retail stores and bars. The company also supplies fixtures for commercial and residential lighting.

"Bruni has a strong interest in our current products, as well as those on the drawing board, and is able to get these into the channels which it serves," says Schmidt. "They also expressed to us a deep interest in being able to support green concepts and initiatives."

Using solid-state lighting, some fixture manufacturers can actually build for less money even given the cost differentials for the actual light source, says Schmidt. For example, when an individual light goes out in a retail store, that space loses all of its sales-per-square-foot value to the retailer. The use of SSL fixtures provides the immediate capability to prevent this loss. "A standard cost-of-ownership calculation already includes labor and product costs for replacement, but if you are able to add the ability to forgo lost sales, this can often tip the equation," he says.

Also, in general, the ability to have an almost heatless light source that can be integrated into furnishings is another compelling value proposition. Manufacturers can also save money by not having to allow bulbs to be changed, or to accommodate ballasts. "Solid-state lighting fixtures essentially last for the useful commercial life of most furnishings; many hotels and bars are refitted within about two years." ●

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Cyberlux: www.cyberlux.com

On our website:

Cree unveils 3-watt XLamp power LEDs
http://ledsmagazine.com/articles/news/2/8/15

Test lab rates Cyberlux LED lighting products at 55 lm/W
http://ledsmagazine.com/articles/news/2/6/33

Cyberlux teams with Bruni to promote LED lighting
http://ledsmagazine.com/articles/news/2/7/25

LED experts converge at the Solid State Lighting conference

General illumination, white LEDs and pulse-width modulation were among the subjects discussed during the Fifth International Conference on Solid State Lighting, writes **David Nicol**.

Speakers from academia, industry and government were present at the Fifth International Conference on Solid State Lighting hosted by The International Society for Optical Engineering (SPIE) in San Diego, California, during the first week of August. More than 30 different academic and industrial institutions were represented.

George Craford of Lumileds opened the conference with a plenary presentation discussing general aspects of the LED industry. He noted that LEDs already dominate colored light applications, and 30–80 lm/W white LEDs are available commercially while figures of 70–100 lm/W have been reported in the lab. Craford indicated that the timing of significant penetration into the general illumination market is hard to predict; however, he did predict that flat-panel televisions will be the next big market for the LED industry. In addition, Craford briefly discussed the Luxeon K2, Lumileds' new line of devices. These can be driven at 1500 mA, and have a low thermal resistance of 9 °C/W.

Jim Brodrick from the US Department of Energy covered an important topic, namely funding opportunities within the DOE's Solid State Lighting program. At the time of the conference, the program received a huge boost with the legislative approval of the Next Generation Lighting Initiative (see p6).

Systems and applications

Osram Opto Semiconductors discussed LED illumination applications and presented a design for an LED reading lamp based on their Golden Dragon LED. The lamp was designed to be positioned flat against the ceiling of a car, to deliver light to an area not directly under fixture, and to have a PCB for proper thermal management to ensure long life and low operating temperature. Additionally the Maserati Birdcage 75th Concept car was discussed (see figure 1) – this has LED headlights powered by 12 RGB OSTAR modules (see "Osram, Hella supply automotive LED lighting" for more details).

Tasso Sales of RPC Photonics described the company's Engineered Diffusers™ for use in SSL. The products can shape LED light into a variety of patterns, two of which are shown in figure 2. Of particular importance for LED applications is the fact that Engineered Diffusers are highly efficient, limited only by surface (Fresnel) losses. In the absence of antireflection coatings, transmission efficiency is about 92%.

William Parkyn from Tailored Optics presented various LED-based linear lighting systems for shelf and cove lighting. The product shown in figure 3 is capable of uniformly lighting an area with a width of about 20 inches from a distance of 12 inches. With this product LEDs can be used in place of linear lights such as fluorescent tubes that are normally used for shelf lighting applications.

John Lundberg and Jeff Singer blinded the audience with their demonstration of a fuselage-mounted anti-collision light (figure 4) using red LEDs. They noted that this device, developed by Honeywell, has much improved robustness over the current flashbulb technology that needed replacement after each landing on rough runways.

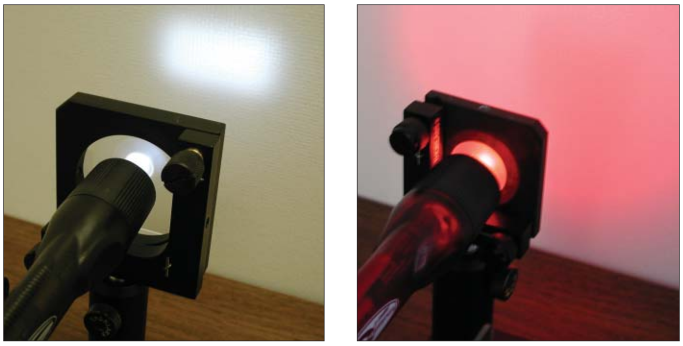


Fig. 1. Headlights of the Maserati Birdcage 75th powered by 12 RGB OSTAR modules. (Courtesy Osram Opto Semiconductors.)
Fig. 2. Engineered Diffusers™ enable homogenization and shaping of LED sources. (Courtesy Tass Sales, RPC Photonics.)

Also from Honeywell, Scott Mangum reported on LED-based aerial refueling lights. These provide added reliability, brightness, and efficiency over the current products. In addition, these products remain stable even through the significant heat cycles that are experienced with the altitude changes in a normal flight.

On a humanitarian note, David Irvine-Halliday from the Light Up The World (LUTW) Foundation gave an overview of his program. He mentioned that one-third of the world's population is without light and even small amounts of light provided by solid-state lighting can make a huge difference to people's lives. →

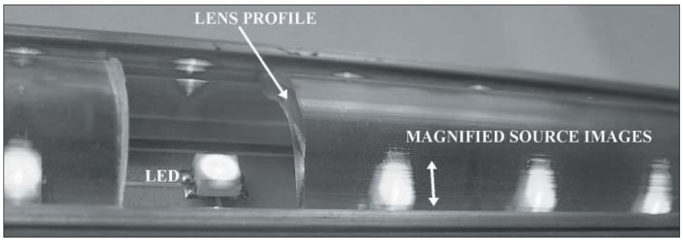


Fig. 3. View from 53° slant of linear luminaire. Magnification produces the required lateral intensity increase. (Courtesy William Parkyn, Tailored Optics.)

Fig. 4. Fuselage-mounted anti-collision lights utilizing high-power LEDs. (Courtesy Jeff Singer, Honeywell.)

White LEDs

The conference contained a number of reports on the creation, control and application of white LEDs. Bill Kennedy of Toyoda Gosei discussed the company's "True White" product consisting of a 390 nm LED pumping a phosphor mixture, which achieves a CRI of 90.

K Kobashi from Yamaguchi University in Japan discussed a high CRI white LED with efficiency of 30 lm/W for use in medical endoscopes. Christoph Hoelen of Philips Lighting reported on efforts to control multichip sources, noting that a temperature and flux feedback system achieved the best results for a reasonable cost.

David Nicol from Georgia Tech showed that three-terminal dual-wavelength LEDs combined with multiple phosphor combinations can be used to create a broadband, spectrally dynamic solid-state light source, thereby incorporating the advantages of multichip and phosphor converted LEDs.

Marc Dyble of the Lighting Research Center at RPI discussed the impact of dimming LEDs by current control and pulse-width modulation (PWM). A large chromaticity shift was observed for dimming of a multichip RGB LED system by either current control or PWM. From this observation it was concluded that an optical feedback system is necessary for dimming of multichip LED systems (see p20).

Substrates and materials

Yongjo Park from the Samsung Advanced Institute of Technology (SAIT) presented SSL developments in Korea. Among the highlights of Park's presentation were Corrugated Interface Substrates, p-type patterning, p-electrode patterning and random *in situ* surface roughening. The *in situ* surface roughening, using DTBSi as the silicon dopant source, leads to a 32% increase in light output, while hemispherical corrugation of the substrate led to a 60% increase in light output as measured on-wafer.

Steve DenBaars of UCSB and Nathan Gardner of Lumileds presented separate work on GaN growth on alternative planes of sapphire and SiC such as the a, r or m-planes. LEDs can be grown on these substrates that emit ~70% polarized light and may have uses in LCD backlights or other applications. Also, due to the lack of spontaneous polarization in the quantum wells, it is believed that the internal quantum efficiency of the LEDs can be improved.

This year, an entire session was devoted to work with ZnO in SSL. Cermet's Jeff Nause reported on his company's ZnO substrate technology with etch pit densities on the order of 10^4 cm^{-2}. Ian Ferguson from Georgia Tech discussed successful efforts to grow GaN and InGaN on ZnO substrates via MOCVD.

The session also included reports on various growth methods including sputtering and ICP-MOCVD. M Jamil, of University at Albany, reported on GaN grown on silicon with defect densities of 2.5×10^7 cm^{-2} and rms roughness of 0.45 nm using a 15 nm ion-implanted N buffer layer.

Light extraction from GaN-based LEDs was another focus of the conference, with D Kim of Seoul National University (South Korea) discussing photonic crystal layers that provide a light extraction enhancement factor of 2.1. Meanwhile Y Soon of SAIT gave a detailed report of Samsung's *in situ* surface-roughening techniques which provide a light extraction enhancement factor of 1.4 over planar LEDs.

OLEDs

Among a number of OLED papers was an announcement from Universal Display that it had demonstrated a white OLED lighting panel with an efficacy of 30 lm/W, using the company's PHOLED™ phosphorescent OLED technology. Power efficiencies of this 6 × 6 inch prototype panel were measured at color temperatures between 2900 and 5700 K. The record 30 lm/W white OLED power efficiency was achieved at a color temperature of 4000 K; these figures are comparable to a cool fluorescent lamp. By comparison, typical incandescent light bulbs emit light at around 15–20 lm/W with a color temperature of 2900 K (see "Universal Display announces 30 lm/W white OLED"). ●

About the author

David Nicol is an electrical engineering PhD student focusing on solid state lighting at the Georgia Institute of Technology, and assists in organizing the annual International Conference on Solid State Lighting. E-mail: dbnicol@ece.gatech.edu.

Links

SPIE conference program: http://spie.org/Conferences/Programs/05/am/conferences/index.cfm?fuseaction=5941

On our website:

Report from the Fourth International Conference on Solid State Lighting (2004)
www.ledsmagazine.com/articles/features/1/8/10

Drivers control 144 LEDs, avoid patents

Tryka LED Ltd

As well as unveiling its new Module 36 Interior (www. ledsmagazine.com/ press/ 10010), Tryka LED Ltd unveiled the IDS-4 and IDS-12 Intelligent Drive Systems, which control up to 144 LEDs each. The units attracted a great deal of attention at PLASA since they use pulse amplitude modulation (PAM), an alternative to the more common pulse-width modulation (PWM). PWM is the subject of numerous highly contentious patents owned by Color Kinetics.

The Tryka drivers use PAM in combination with closed-loop thermal feedback to optimize the LED lifetime. This so-called colour cool technology is patented in Europe, the US, Australia and Japan. The US patent application number is 20030057888.

The drivers have seven modes such as static color, cross-fade and cyclic wash, with several pre-sets available for each mode. IDS-4 controls 18–36 LEDs from each of four RJ45 outputs, while IDS-12 has 12 outputs able to drive 6–12 LEDs each.

www.tryka.co.uk

Long-throw fixture uses 2° optic

Xilver

The Xolar LT is a batten-shaped long-throw lighting fixture designed for touring and installations. The standard 2° optic (4° with beam homogenizing filter) creates a parallel light beam resulting in an intense homogeneous colored beam, easily capable of throwing 100 m. It is ideal for cycloramic or long-throw applications. The Xolar LT contains 16 segments either as individual, sectional or a single unit, and is controlled via DMX and the Xilver serial interface. Each segment uses Xilver's unique patent-pending color-combining system. The Xolar LT is calibrated to achieve a consistent and stable color output throughout changing temperatures. It features a total of 48 LEDs – 16 red Luxeon I, 16 green Luxeon III and 16 blue Luxeon I – controlled in a 30-bit modified smooth resolution.

www.xilver.com

Lighting controller wins Innovation Award

Pharos

Pharos, distributed by TMB, won a PLASA Innovation Award for its Lighting Playback Controller (www. ledsmagazine.com/ press/ 9975). A control system for entertainment and LED lighting in an architectural setting, the Pharos supports DMX or DALI color mixing fixtures, dimmable ballasts and automated lighting. The judges felt that this was a "beautifully engineered lighting controller".

www.pharoscontrols.com

Fixture utilizes latest Lumileds LEDs

James Thomas Engineering

New products from James Thomas (www. ledsmagazine.com/ press/10025) included the PixelEight LED "blinder", one of very few products to utilize Lumiled's new Luxeon K2 device and the PixelLine 96 Batten. This latter product fixture contains 96 Luxeon LEDs (24 each of 1 W red and amber and 24 each of 3 W blue and green) over six cells, stretched into two rows to enable the seamless forming of lines with multiple fixtures – for effects like highlighting and set dressing.

www.pixelpar.com

Panels combine video effects and lighting

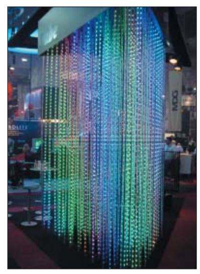
Traxon

The Mood Light Tile 64PXL DMX from Traxon is a 50 × 50 cm tile containing 64 RGB light sources that can be illuminated individually. The LEDs are mounted onto a back panel and Traxon is now manufacturing and selling the panels as well as the complete systems. LEDs are supplied by Cotco. Several 64PXL panels can be interconnected and jointly controlled via DMX. Visually mesmerizing images – both static and animated – as well as text and movie files, can be displayed. These features place the 64PXL panel halfway between LED lighting effects and LED video screens.

www.traxontechnologies.com

Hanging LED tubes create 3D displays

G-LEC



Following on from its LED display frames, G-LEC has now developed the Tube, a set of frameless lightweight and flexible tubes containing LED pixels mounted on a linear PCB. Each pixel contains three LEDs with a total brightness of 800 mcd. Tubes can be cut to length and hung to make a 3D presentation. Also, G-LEC has now integrated quieter fans into the frames of its PhantomFrame product, to draw air up through the tubes and provide cooling. The pixels in the PhantomFrame contain five LEDs and have a brightness of 5100 mcd.

www.g-lec.com

Developer kits for BL-4000 light sources

Lamina Ceramics

Lamina is now offering developer kits for its award-winning BL-4000 products. The kits are available for Lamina's RGB+ and 5500 K white LED light sources. The kits are complete with Lamina light sources assembled on heat sinks and with commercially available drivers and Lamina optics. Lamina developer kits are ready to plug in upon arrival! The RGB+ Kit can be used worldwide with universal voltage input (100–240 VAC) and DMX input capability. The 5500 K White Kits are available in both low voltages (120+/– 10% VAC) and high voltages (230+/–10% VAC).

www.laminaceramics.com

IC drives solid-state lighting systems

Melexis

The MLX10803 is designed for automotive interior and exterior lighting or any applications that require temperature compensation, low noise and high efficiency at lowest possible system cost. The IC includes several reference inputs designed to allow external sensors temperature compensation in order to guarantee a constant light output or light level and to protect both LEDs and surrounding circuitry against overheating. Operating normally from a DC supply of 6– 32 V, a minimum of external components can be added to allow the IC to operate on 115 or 220 V, 50–60 Hz AC. It can efficiently drive a virtually unlimited number of high-intensity LEDs in the range of 1–1000 W with appropriate external discrete power devices. MLX10803 offers superior performance in temperature compensation and intelligence such as dimming and soft increase of light level at start-up. Typical efficiency rates vary between 70% for single LED applications and more than 95% for LED array applications.

www.melexis.com

ACULED all-color ultrabright platform

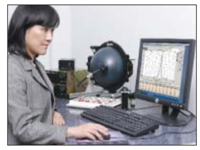
PerkinElmer Elcos GmbH

The ACULED All Color Ultrabright LED is a high-power light source utilizing multi chip-on-board (COB) technology. It is a compact, multi-use LED designed for operation in a variety of specialty lighting applications including mood lighting, vision systems, architectural lighting and medical lighting. John Roush, president of PerkinElmer Optoelectronics, said: “We are delighted to be rolling out the ACULED RGB LED platform and are excited about the range of innovative specialty lighting and medical applications that can benefit from its excellent color mixing and brightness.” PerkinElmer Elcos is offering ACULED Evaluation Kits so that customers can test the RGB LED platform with their particular applications.

www.elcos.de

SLMS LED series for high-speed testing

Labsphere

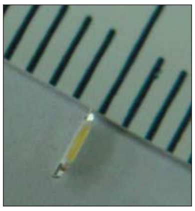


The SLMS LED system offers a practical high-performance solution for R&D, quality assurance, and manufacturing engineers of packaged LEDs. These powerful systems

simplify complex spectral measurements through both software and design. The SLMS LED software guides users through testing, providing results in milliseconds, including total spectral flux, luminous flux, chromaticity, color rendering index (CRI), and dominant wavelength. The system also enables the correction of absorption errors, reducing flux and color measurement result errors by up to 15%. The hardware is designed for easy access to the device under test as well as for a variety of testing environments, such as externally mounted LEDs. The system ensures NIST traceable results and on-site recalibration with total spectral flux lamp standards, cutting down on time lost due to equipment maintenance.
www.labsphere.com/products.asp?parent_id=67&catId=307

LEDs enable slim cellphone LCDs

Seoul Semiconductor



SSC has developed the world's slimmest side white LED, with a thickness of 0.45 mm, compared with typical side white LED products which are 0.6–1.0 mm thick. Very slim white LEDs are in demand because of the trend for thinner mobile phones, which in turn makes it necessary to reduce the thickness of the LCD backlighting unit. SSC has already delivered samples of the new LEDs to customers. With continuous investment in R&D as well as improving technologies, SSC says that will capture the slim-sized white LED market in advance and aggressively focus on increasing domestic as well as overseas market share. The company expects that the next generation of phones will require LEDs as thin as 0.3 mm.
www.seoulsemicon.com

Visual Patch enables rapid fixture set-up

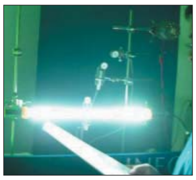
Artistic Licence

The Visual Patch is described as "the ultimate time-saver for converged lighting and video applications". It creates an on-screen geographic map of a two- or three-dimensional pixel array. The camera detects the size, shape and position of the illuminated pixel, maps the data to screen coordinates and sets the pixel's DMX512 start addresses via RDM. Visual-Patch is built into Artistic Licence's Colour Tramp lighting control system and will also be available under licence to other manufacturers. The company says that it is already developing the next generation of Visual-Patch which uses multiple camera positions to generate a 3D map of the stage.

Artistic Licence also unveiled Pixi-Web, a modular system for rapid assembly consisting of 16 RGB LED nodes mounted on a lightweight, flexible webbing. The system is also available as Color Web from AC Lighting. The 1 × 1 m panels can be clipped to other panels, allowing large areas to be covered quickly and easily. The webbing occupies only 10% of the total area, so can be placed in front of objects or light sources, or over speaker stacks.
www.artisticlicence.com

LED Tube Light replaces fluorescents

NeoPac Lighting



The LED Tube Light is marketed as the first LED-based fluorescent replacement. It consists of two point-light-source NeoBulb Light Engines coupled into high-transparency, partially reflective polycarbonate light pipe to offer hundreds of lumen output. The actual luminous flux depends on the performance of the selected NeoBulb Light Engine. The thermal management design of the NeoBulb source, using a finned heat pipe, is capable of maintaining the LED junction temperature at around 75 °C to ensure long lifetime. In July, NeoPac demonstrated a 20 W NeoBulb source with an output of 500 lm (see www.ledsmagazine.com/press/ 9495). NeoPac says that this type of light source will be in demand as regulations come into force for phasing out the use of mercury-containing fluorescent light sources.
www.neopac-lighting.com

Send us your product news

Submit press releases using our online form at

www.ledsmagazine.com/press/add

Corrections to the July issue of *LEDs Magazine Review*

Additional information has been supplied to us in relation to two of our previous articles .

LED dragon breathes fire into Japanese attraction

In the Dragon Tower article (*LEDs Magazine Review* July 2005 p22) please note that Stone Mountain productions was the initiator of the design to wrap the LED video screens around the concrete foundation tower that became the Dragon Tower in Enoshima Island, Japan. Stone Mountain says that the Dragon Tower is part of a continuing series of innovative LED video display concepts to integrate LED video screens within the architectural exterior design of a building, including theme parks, urban city centers and retail environments. Contact: bob@sml-pro.com. Web: www.sml-pro.com.

Ambient experience: LEDs soothe hospital patients

In the Philips article on its Ambient Experience hospital suite (*LEDs Magazine Review* July 2005 p30), the name of the LED-based lighting fixture that was integral to the adjustable lighting effect was omitted. The luminaire in question is the Destiny CV from TIR Systems. Web: www.tirsys.com.

The Destiny CV luminaire is a linear source containing 12 Luxeon LEDs per foot. Here it illuminates the curved roof segments.

LEDs MAGAZINE

Multi-watt LED light engines offer challenges and opportunities

Multi-watt class LED array light engines are emerging as viable replacements for current light sources. As **Gareth Jones** of Enfis describes, this brings new opportunities for application developers, as well as challenges for systems designers.

Over the last few years there has emerged a new class of light emitter which is able to compete in terms of light output and efficiency with the more traditional light sources such as incandescent, halogen and arc lamp technologies. This new light source, commonly known as the high-power LED light engine, has been built upon the developments of a small number of LED chip companies such as Osram, UEC, Arima Optoelectronics and CREE – some of the larger industry players who provide access to their best LED chips.

In addition, a small number of companies such as Lumileds, Osram, Cree, Nichia, Optodiode, Epitex, Lamina Ceramics and Enfis have developed efficient LED packages which have enabled these chips to be driven at high power while also allowing the heat to dissipate effectively. This is also coupled with efficient thermal management techniques and high-efficiency, low-cost electronic driver technology to bring about the Multi-Watt (MW) LED light engine.

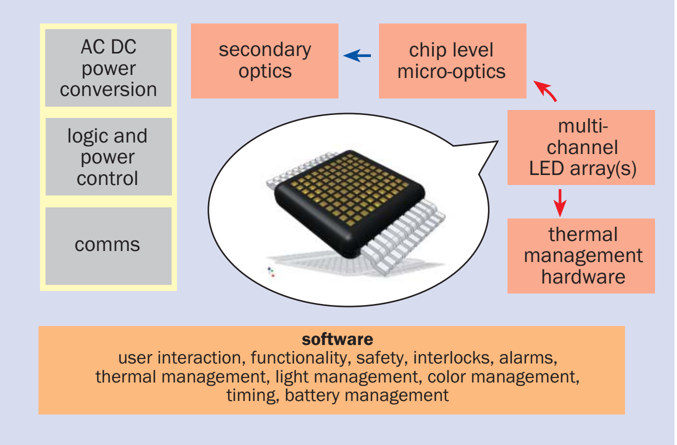


Fig. 1. Light engine component block diagram.

Scaling approaches

There are two main approaches for the generation of traditional lighting-scale lumen values from LEDs. One approach favored by companies such as Lumileds (and the far eastern clone companies now producing Luxeon look-alikes), Cree and Osram is to produce single power chip LED packages which can be attached to PCBs in tight clusters to produce reasonably high output powers. However, there is a sacrifice in the thermal management and the maximum radiative power density that may be available to such approaches.

The other approach utilizes the packaging of a large number of small or power LED chips onto thermally efficient tiles which provide a very high-power density and thermally efficient light-emitting arrays. An advantage of this approach is the ability to integrate multiple wavelengths (or colors) within the array to produce white light, for instance. This technology is favored by companies such as Optodiode, Lamina, Epitex and Enfis. The arrays can be monochromatic, or a combination of colors such as red, green and blue or a combination of LED and phosphor for white light emission.

Enfis has invested considerable resource in the development of MW LED arrays and is able to achieve power density levels in excess of those on offer from the majority of "off-the-shelf" LED companies (see Table 1). The company believes that the integration of our MW-LED arrays with the other essential components of the light engine such as power conversion, optics, thermal management and the manufacture of the plug and play light engine into medium cost niche lighting applications will enable competitive LED based illumination products to become widespread.

Light engines

The array is not the whole show – indeed it cannot be used effectively without some other important light engine system components.

Table 1. High-power LEDs

Company name	Part no.	Size (cm)	Area (cm^2)	Light output	Radiant power density (mW/cm^2)	Thermal resistance (°C/W)
Lamina	BL-3000-red (λ_d ~ 618 nm)	27 × 32	8.6	6800 mW 1938 lm	790	<1
Lumileds	Luxeon III red (λ_d ~627 nm)	8 × 15	1.1	770 mW 140 lm	690	15
Enfis	MW-5x5-red (λ_d ~ 625 nm)	9 × 12	1.1	4000 mW 880 lm	3700	<1

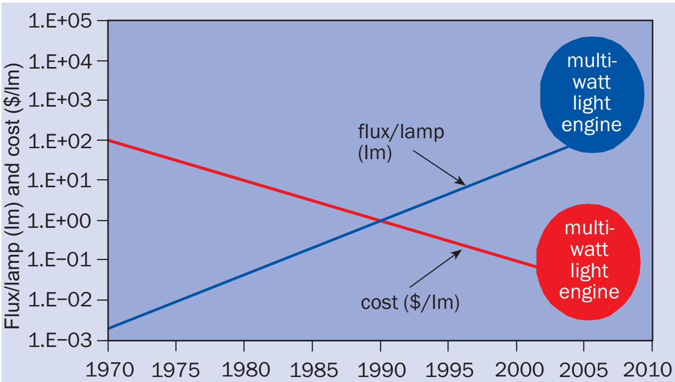


Fig. 2. Changes to the LED cost/performance landscape enabled through the development of MW-LED arrays.

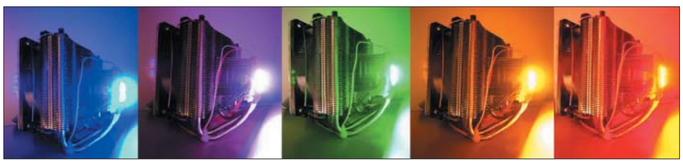


Fig. 3. Digital light: Enfis MW-LED light engines using RGB color mixing to generate instant color changing over a wide color range.

Around these arrays lie the thermal, electronic and optical management systems. Figure 1 (p35) shows a schematic block diagram of the typical components in a light engine.

The need to drive more power through these LED arrays whilst providing improved longevity, higher wall plug efficiency, lower cost and smaller form factor presents the light engine designer with a number of challenges with respect to the component blocks shown in figure 1 (p35).

Market predictions

Roland Haitz described a trend in the light output per lamp and cost per lumen according to the curves, shown in figure 2, in blue and red respectively. These predictions are similar in nature to predictions made by Gordon Moore, co-founder of Intel, in the 1960s, that the number of transistors per square inch on integrated circuits had doubled every year since the IC was invented. Moore predicted that this trend would continue for the foreseeable future. Both laws are based around similar types of processes relating to inorganic semiconductors, and show that both cost and packing density can be improved considerably over many decades and will be expected to improve for LEDs over the next 10–20 years.

Recent advances in multi-chip arrays have altered the slope of these curves dramatically, providing orders of magnitude changes in lumens/lamp and reduction in lumens/$. This has brought more applications into the market space for MW-LED light engines.

Crucial to the adoption of MW-LED light engine technology by the wider general lighting market will be two key improvements: the luminous efficacy (lumens out to electrical watts in) and the cost per lumen.

Lighting is dominated by the various light source technologies which have the following luminous efficacies:

- Incandescent, 10–15 lm/W
- Halogen, 15–20 lm/W
- LEDs (2005), 20–25 lm/W
- Fluorescent, 50–95 lm/W

However, the luminous efficacy of LEDs is set to increase at a dramatic pace fuelled by key government investment particularly in the US and Japan. Recent laboratory results from Cree showed 70 lm/W for their XLamp single die package, and forecasts now indicate that around 150 lm/W will be achieved within the 3–5 years.

These improvements will have a profound effect on the size, cost and energy savings using LEDs for lighting applications. As an example, the power consumption equivalent for a standard 100 W incandescent light bulb would be reduced using LEDs to around 5–10 W in the coming years!

Niche market applications

Given the current luminous efficacy (lm/W) and cost ($/lm) there exists a number of niche markets ready and willing to accept the MW-LED light engine.

These markets demand high power – from hundreds to tens of thousands of lumens – but are also able to take advantage of the unique characteristics of MW-LED light engines. These niche applications are accessible since they will pay a price suited to the current cost structure in the LED light engine industry. The technology is available and improving, while the price is just acceptable and improving. Some examples of niche illumination markets for MW-LED light engines are:

- medical and dental lighting
- entertainment/stage and architectural lighting (figure 3 shows an Enfis MW-LED RGB light engine providing approx. 10,000 lm)
- industrial task lighting

In addition there exists a large number of other niche applications not usually associated with lighting such as:

- light based medical treatments – see facial treatment device as depicted in figure 4
- non-destructive testing
- curing of sealants and adhesives
- automotive headlamps
- large area LCD backlighting

Desired system characteristics

The next-generation light sources for medical, industrial and niche illumination applications will require certain key product design fea-

Fig. 4. Enfis medical MW-LED Light Engine system for skin treatments.

Table 2. Wish-list of features for MW-LEDs

High power output (kilolumen level) for illumination applications
High power output density i.e. high radiant intensity provides for compact optical solution and small mechanical form factor.
Compact efficient thermal management to remove heat
Small size – low weight
Long lifetime – low maintenance
Intelligent light source smart operation – feedback temperature, color etc
End of lamp life indication prior to lamp failure
Networked communications enabled (such as DMX, DALI etc to allow designer to use these light engines as plug and play component)
Plug and play mains 110 V or 240 V, low voltage 12/24 V or battery operable
Color selection – ability to vary color temperature and keep high CRI. (In some instances to provide enhanced CRI through the use of other colors in addition to RGB)
Digital light control – selection color or light level and system will maintain these levels to the end of life through closed loop feedback
Maximise CRI through the use of multiple emitters or broad phosphor emission
Controlled linear dimming features

Table 3. Key design factors for MW-LED arrays

Use LED chips with high reliability – the lifetime of the chip is the dominant initial parameter
Use LED chips with high efficiency to reduce heat
Use LED chips which allow lowest thermal resistance path from the active region to the base of the chip
Ensure LED chips are attached to the package with low thermal resistance
Avoid moisture and other contamination near the chip and during the packaging process
Provide low stress encapsulation scheme or dry gas sealing (especially for UV)
Keep LED chip junction temperature as low as possible
Use high thermal conductivity packaging
Ensure match of thermal expansion coefficients between LED chips and package
Provide efficient thermal management to remove heat from the back of the package
Ensure that the wire bond is safely rated
Avoid fusing through transients in testing, handling or in the system
Minimize temperature cycling
Ensure good electrical circuit design and connections from array

tures so that they may compete and add value to these markets where more traditional light sources and laser light sources dominate. Some of these "wish-list" design features are shown in Table 2.

Of course, to compete in all of these markets still requires the system to be competitive on price. This price point then sets a number of challenges for system designers to include as many features as they can whilst still providing a competitive product in fierce global markets.

The combined features above lead to the formation of a new light source: the MW-LED light engine with digital light network enabled functionality. Enfis is working closely with customers and suppliers to meet the needs of the niche illumination markets so that the right price can be offered with the right feature sets. A number of design challenges do exist to achieve real market penetration in the multi-watt range with cost being one of the biggest barriers to wide-scale adoption.

Design challenges

New higher power niche applications for MW-LED light engines are providing LEDs with applications in less cost sensitive markets compared with the traditional indicator lamp markets. However, in most cases there is already an entrenched competing light source which is better either in terms of efficiency, or cost, or power density; these values need to be surpassed for the LED product to gain market share. MW-LED light engines can offer strong additional benefits such as color mixing, dimming and reliability, but they must also be able to compete in the more mainstream areas such as cost, luminous efficiency and overall system size.

MW-LED arrays

Most MW-LEDs consist of a large number of LED chips on a thermally efficient base package. There are a variety of design choices with no standardization yet taking place. A lack of standardization provides challenges for system integrators and tends to "lock in" certain systems manufacturers to use particular suppliers, which can lead to a lack of competition and higher costs.

When electrical power is applied to an LED chip, between 70–95% of this power is dissipated as thermal energy (i.e. heat). This must be conducted away from the chip effectively to prevent catastrophic thermal failure of the LEDs and surrounding materials such as encapsulation. Thus, control of the temperature within the LED array is hugely important and is a large contributing design factor affecting the reliability of the system.

Some of the key design factors which enable high reliability MW-LED arrays are shown in Table 3.

There are two approaches which one can take regarding the reliable use of MW-LED array technology and consistent operation at higher powers:

- ensure LED chips reliably and efficiently operate at higher temperatures – requires packaging and encapsulation innovation, but does not require bulky thermal management systems
- remove heat from LED array/package to maintain low LED chip temperature – integrated thermal solutions requiring less array process development but ultimately resulting in larger system footprint

Both of these directions are important to enabling the use of MW-LED array light engines in general lighting applications.

Thermal management

If the heat cannot get away from the base of the package then the array will heat up and this will quickly result in poor system performance and reliability. Therefore providing efficient, low-cost, low-power consumption and small size heat dissipation systems to remove heat from the base of the array is a key technical challenge.

Figure 5 (p38) shows the difference in the thermal challenge between LEDs and incandescent light sources. LED systems are required to conduct the heat away from the chips and radiate no significant heat; whereas the majority of the heat generated within an incandescent naturally escapes into the environment through radiation.

There are generally three major stages in the removal of heat from a MW-LED array:

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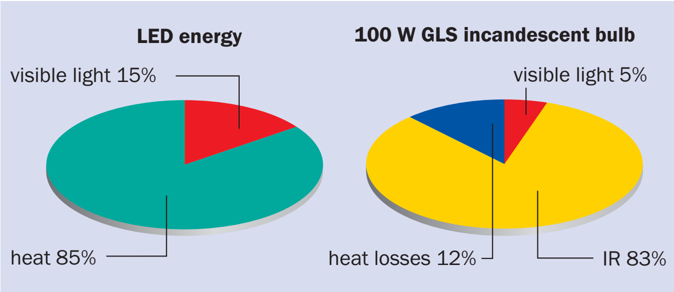

Fig. 5. The comparison between the energy conversion of an LED and an incandescent light bulb showing the difference in the type of energy generated.

- Primary thermal transfer from the LED chip to the base of the array is usually conduction. The chip must be in good thermal contact with the package and the package must be in good thermal contact with the conductive heat exchange system. In addition, the package itself must have low thermal resistance
- Secondary thermal transfer transports the heat from the base of the array efficiently and then spreads the heat out so that it can be removed via convection
- Thirdly, convective processes such as fans and fins can be used to transport the heat into the surrounding air

Each of these processes requires careful design and usually computational modeling to ensure that the transfer processes are optimized in terms of size, choice of materials etc. This must take into account the structural requirements of the overall system i.e. the shape and size constraints.

The above three phases are relevant for the more traditional heat exchange systems i.e. forced air cooling or fluidic cooling systems. Other highly-efficient technologies are now being developed that have the potential to reduce the size of existing systems but are beyond the scope of this article.

Optical management

MW-LED arrays are not point sources of light but are generally classed as extended sources with multiple elements and highly divergent emission. This can be an advantage where the spread of light is useful but in general, where one wishes to have control over the distribution of light, it creates problems with the efficient collection of light. This leads to the requirements for a complex optical solution.

Novel optical approaches are necessary to keep efficiency high whilst retaining compact size which can lead to high costs for new optics and tooling. Many companies are developing a wide-range of optical solutions for MW-LED arrays using traditional lenses, reflectors, total internal reflection in plastic optics, and micro-lens arrays, as well as combinations of these. However, due to the lack of standardization in the design of the arrays there is no standardization in the optical solutions yet.

Electronics and power management

LEDs are generally DC-driven although some companies have been working on direct drive from AC supplies. The power conversion process from AC to DC introduces inefficiencies into the system, and this in turn introduces extra cost and also increases the size of the system. Also, there are important issues such as EMC and safety requirements which must be met.

Once the power conversion process has been performed the electronics are then required to control the current through the LED. This can be an issue when variations exist between the electrical characteristics of individual LED chips and therefore LED arrays. Such variations are widely referred to as "binning" issues and must be taken into account in the design process if reproducible systems are to be manufactured.

As the systems are driven smaller and produced at lower cost, each constraint reduces the available design space with traditional PCB design. New technology approaches are necessary such as integration of the electronics and optoelectronics into compact, thermally efficient packages. These take in AC power and provide all the necessary power conversion, control and intelligence within a small number of compact chips.

Conclusions

Multi-watt class LED array light engines have emerged and are creating new opportunities to replace current light sources for illumination. These MW-LEDs bring new opportunities for application developers, as well as challenges for systems designers.

Moving forward, there is a requirement to move towards standardization of arrays, connectors, optics, thermal management systems and electronic designs in order to reduce costs. There is also a requirement to move towards integration of electronics and optoelectronics in order to improve thermal efficiency, footprint and cost. ●

About the author

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