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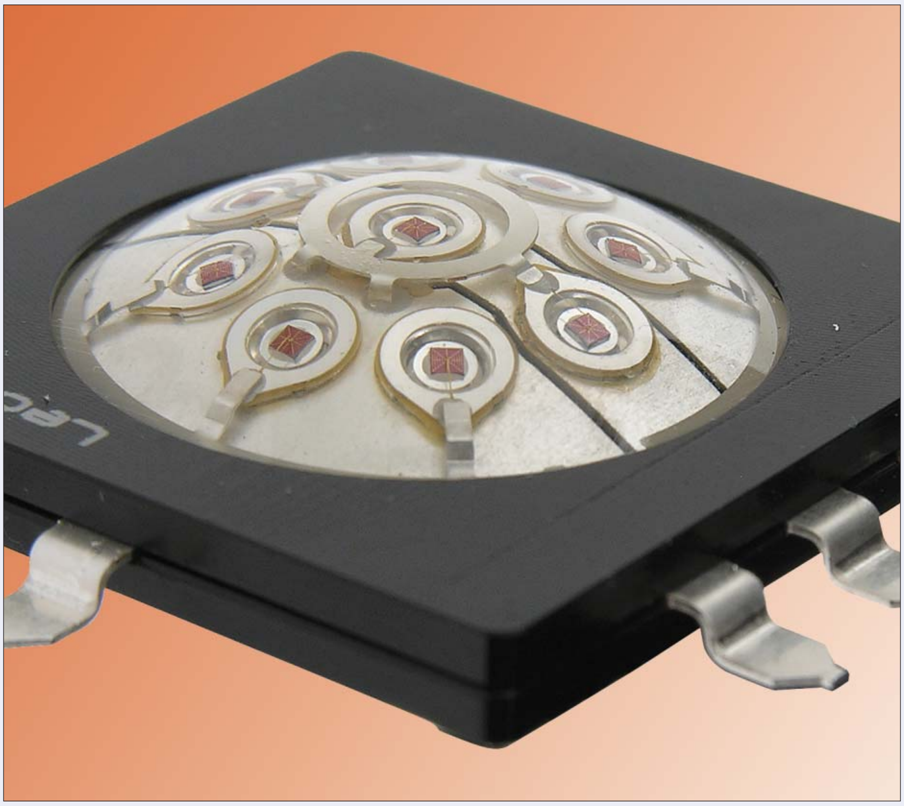


This unique dome-shaped package from Lednium can accommodate multiple high-power LEDs. **p15**

AlbEO's Repleo lighting system contains more than 800 white LEDs in 5 mm packages. **p19**

Several hundred thousand RGB LEDs illuminated the Lexus booth at the Frankfurt Motor Show. **p33**

BUSINESS

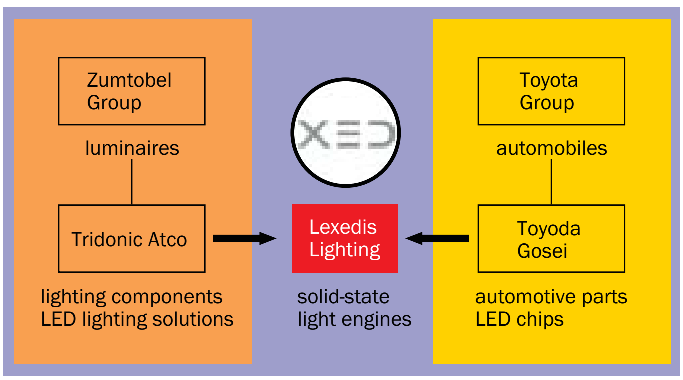
Lexedis Lighting proclaims 'the rebirth of light' at launch

Lexedis Lighting GmbH, the LED lighting company formed in May 2005 as a joint venture between Tridonic Atco and Toyoda Gosei, was officially launched in mid-December at Toyota's recently redesigned showroom in Paris, France.

Tridonic Atco, an Austrian-based supplier of lighting components and LED lighting solutions, is a subsidiary company of the Zumtobel Group, a leading lighting manufacturer. Toyoda Gosei is a pioneer in InGaN LED technology and a leading supplier of high-brightness LED chips. Japan-based Toyoda Gosei also supplies automotive parts and is a subsidiary of the Toyota Group, which explains the location of the Lexedis launch event.

Lexedis, based in Jennersdorf, Austria, is now the center of competence for both parent companies in the field of solid-state light engines. The company has inherited a strong intellectual property arsenal in light conversion, chip architecture, packaging design and numerous other innovations.

Lexedis will concentrate on high-power emitters, and will use inorganic packaging materials and glass optics, as well as developing new phosphor materials and methods of application. Tridonic will continue to focus on chip-on-board LED technology, which has advantages in specific applications. The high-power LED packaging efforts carried out by Toyoda Gosei in Japan will now be centered at Lexedis,



Lexedis is a joint venture between LED manufacturer Toyoda Gosei and lighting component supplier Tridonic Atco. The new company will benefit from the expertise of its parents on the lighting side (via Zumtobel) and on the automotive side (via Toyota), although a large proportion of Lexedis's sales will be to external companies.

Links

Toyoda Gosei: www.toyoda-gosei.com/led
Tridonic Atco: www.tridonicatco.com

On our website:
More information and product photos
www.ledsmagazine.com/articles/news/2/12/16
Tridonic and Toyoda Gosei sign joint venture agreement
www.ledsmagazine.com/articles/news/2/3/17

and the Japanese company will focus on its core competency in high-power LED chip technology. Lexedis will move into a purpose-built, fully automated assembly facility in early 2006.

Lexedis products

Instead of talking about LED-based products, Lexedis claims to have created a new species of solid-state light engine,which it has named XED. Says Lexedis: rather than being an acronym, XED represents "a significant evolution and possibly revolution in the nascent solid-state lighting industry, and stands for dynamic, powerful, innovative and durable light engines designed to provide 'light for life' ".

The first XED products from Lexedis will be:

- **The miniXED** – a miniature (2.8 × 3.4 × 1.15 mm) surface-mount solid-state light engine. Ranked as a 2 W device, it features a light output of 35 lm, and a very low thermal resistance of only 10 °C/W. Its ceramic package and wireless bonding ensures the highest durability and lowest lumen depreciation in its class. The miniXED is now available at a color temperature of 4000 K.
- **The XEDlamp** – an ultra-compact spotlight (17 × 21 × 11 mm) that incorporates the miniXED light engine. With an aluminum die-cast body and a miniature plastic lens, the XEDlamp features an illuminance level of 300 lx (without heat sink) and perfect uniformity. The lamp is ideally suited for customers who require plug-and-play solutions.
- **The powerXED** – now under development at the Lexedis European R&D center in Austria. This surface-mount device will be released in 3 W and 5 W versions in 2006. Significantly smaller than all competing high-power LED devices (the package footprint is less than 45 mm^2), the powerXED will demonstrate the superiority of XED technology against LEDs, says Lexedis. It features an integrated miniature glass lens (40°, 60° and 90°), a completely inorganic body, and a thin-layer phosphor coating. The powerXED will be available in all colors with best white-light quality.

The company says that in the coming years it will intensify its

Toyota Motor Europe recently unveiled its redesigned showroom (*Le Rendez Vous Toyota*) located in the Champs-Elysées, Paris, and put LED technology at the center of its innovative multimedia environment. Four large, high-resolution LED screens, supplied by Toyoda Gosei, symbolize the notions of quality, energy saving and advanced technology, which are intrinsic values of the Toyota brand.

product development program. New XEDon light engines for automotive applications will be released, as well as the high-efficiency nanoXED range powered by Toyoda Gosei's new mid-power core emitters. The range of XEDlamp products based on powerXED engines will also be extended, says Lexedis.

CHIP TECHNOLOGY

Osram announces enhanced thin-film LED chip technology

Osram Opto Semiconductors has developed an advanced version of its thin-film LED chip technology, which has already been incorporated into several advanced device-level products. In late November Osram unveiled new Power TopLED packages that are available at two brightness levels and in a different range of colors. The orange Power TopLED, for example, is available in two versions with fluxes of 3 lm or 7 lm, at an operating current of 50 mA.

Osram subsequently announced an addition to its Golden Dragon family of high-power packages that is aimed specifically at automotive applications such as daytime running lights. The device produces a typical luminous flux of 64 lm from an operating current of 500 mA, compared with 40 lm for the previous version, and has a forward voltage that has been reduced from 3.8 V to 3.2 V (typical). The company says that an optimized package, combined with a special carrier material, ensures excellent heat dissipation.

The new products are based on Osram's thin-film chip technology, which has been in production since 2002. The company continues to make iterative improvements to the technology, which is applicable to both InGaN-based devices (known as Power ThinGaN) and AlGaInP-based devices.

The InGaN devices are grown on sapphire and wafer-bonded to a reflective substrate, after which the sapphire is removed. The resulting device has a very thin emitting layer (hence the name) and is a surface emitter, since almost none of the light is emitted from the device's side walls. This has important consequences since it enables the device area to be scaled, and the devices also have a very low forward voltage. The AlGaInP devices are manufactured in a similar way on GaAs substrates, but they incorporate a hexagonal microprism structure to enhance light extraction (see www.ledsmagazine.com/articles/news/1/1/2 for background on the chip processes).

The improved thin-film chip technology features in Osram's Golden Dragon high-power LEDs, which are aimed at daytime running lights.

Performance of white Golden Dragon with lens

	350 mA		700 mA		1 A
	R&D	Typical	R&D	Typical	R&D
Flux (volume converter) (lm)	52	42	85	68	
Flux (chip-level converter) (lm)	62	50	102	89	126
Forward voltage (V)	3.0	3.2	3.3	3.5	3.5
Efficacy (lm/W)	59	42	44	36	36
Wall-plug efficiency (%)	27		22		18

The performance of white Golden Dragon packages with lens, incorporating Power ThinGaN chips. As expected, performance is better for R&D results compared with typical production values.

Power ThinGaN

Using the new Power ThinGaN 1 × 1 mm chips in a Golden Dragon package with lens, Osram has achieved brightness values in R&D of 311 mW in blue and 70 lm in green at 350 mA. Results for white emitters are shown in the table. Values such as an efficacy of 59 lm/W and a flux of 62 lm have been achieved at 350 mA. At low current, the efficacy of these large-area chip packages shows a peak at 89 lm/W. At higher currents, the output reaches 126 lm at 1 A, and the efficacy is still high at 36 lm/W.

As the table shows, the performance of white LED packages is significantly improved by using chip-level conversion technology, in which the phosphor is coated directly onto the top surface of the chip. In the traditional "volume converter" approach the chip is placed in a cup that is filled with phosphor.

As mentioned above, a key advantage of ThinGaN technology is that the chip area can be scaled successfully. Calculations indicate that a 1 mm Power ThinGaN will have around 98% of the total flux compared with a 300 × 300 μm device for constant current density. However, for a sapphire device with a transparent contact the light output is reduced to 85% for the larger chip. For flip-chip devices on sapphire and SiC substrates, the values are 75% and 58%, respectively.

AlGaInP and AlGaAs devices

Osram has already reported red AlGaInP thin-film devices in R&D with an efficiency of 100 lm/W and external quantum efficiency (EQE) of 50% at 20 mA. Typically for AlGaInP material, the EQE falls with decreasing wavelength to around 10% near 590 nm.

The latest chips have been incorporated into Power Topled and Golden Dragon packages, using 330 mm and 1 mm AlGaInP chips, respectively. In Dragon packages with a lens, red 616 nm devices have typical values of 121 lm at 800 mA with an efficacy of 57 lm/W and a forward voltage of 2.5 V (2 W power dissipation). Efficacy is as high as 90 lm/W at 50 mA. The values are roughly 20% less in packages without a lens.

The thin-film technology has also been used in infrared-emitting AlGaAs-based devices at 850 nm and 940 nm. At both wavelengths Dragon packages without lenses have typical values of 470 mW and 40% efficiency for 1000 mA and 1.75 V forward voltage.

MARKETS

Camera phones offer bright spot in handset LED market

By Asif Anwar, Strategy Analytics

Leading LED manufacturers supplying LEDs for LCD and keypad backlighting functions in mobile phones will see total revenues from this market segment fall 41% by 2009. However, this will be offset by strong revenue growth in the emerging camera flash segment. By 2009 revenues from the growing camera flash function will represent 36% of the total handset LED market demand for LED manufacturers.

The mobile phone handset market remains the most significant segment of the high-brightness LED industry. The rapid growth in overall demand for mobile phone handsets, coupled with trends such as the conversion from monochrome to full-color displays, caused the total LED revenue in the handset market to grow to $1.44 billion in 2004.

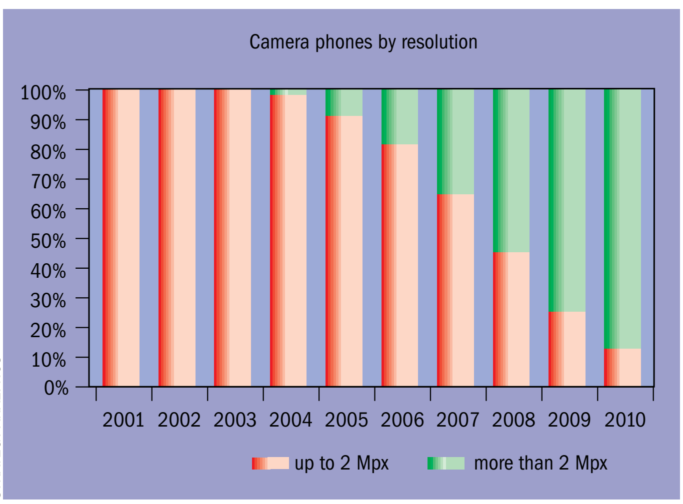
However, Strategy Analytics predicts that overall LED revenues in the handset market will decline by 41% by 2009 for several reasons:

- While annual handset shipments will continue to grow through 2010, when more than 1 billion units will be sold, the rate of growth will slow in the latter part of the decade.
- The introduction of brighter LEDs and more efficient backlighting schemes will cause a net reduction in the average number of LEDs used in both the LCD and keypad backlighting segments of the market. Coupled with the decline in average selling prices experienced in these two segments, both markets will decline between 2004 and 2010.

Camera phones

Fortunately for the LED industry, a new handset market segment is emerging in the form of camera flash, as a result of cellular handsets incorporating digital camera capabilities. Strategy Analytics has identified the camera flash as a key emerging market for LEDs in handsets, and one that will counteract the decline in LED revenue from the LCD and keypad backlighting market segments.

Camera phones are now outstripping sales of stand-alone digital still cameras (DSCs). Shipments of camera phones increased from 3.9 million units in 2001 (1% of total shipments) to 391.7 million units in 2005, which is equivalent to 50% of all shipments. Strategy Analytics expects that by 2010, 77.6% of all handsets will have cameras.



STRATEGY ANALYTICS

SONY ERICSSON

LED flash units are now in an increasing number of camera phones.

Consequently two inter-related trends will increase the demand for fully functional flash units using high-power LEDs:

- First, as handsets are increasingly being equipped with higher-resolution cameras, consumers are beginning to view their several-megapixel camera phone as a viable alternative to a stand-alone DSC. As this trend continues, consumers will demand a flash unit that is commensurate with the performance of the camera, and that is capable of taking good-quality images over a distance of several meters in low-light conditions.
- Second, higher-resolution pixel arrays require more light to achieve the same image quality as lower-resolution arrays under identical conditions (such as light levels and distance from the subject). So, for higher-resolution cameras with smaller pixels a high-brightness flash becomes a necessity rather than a "nice to have" feature.

The first mobile phones with cameras exceeding 1 Mpx appeared in 2003. In 2004 almost 90% of cameras in handsets were of VGA quality or below. Strategy Analytics estimates that by 2007 cameras in the 1–3 Mpx range will comprise more than 50% of the market. By 2010 more than 50% of camera phones will have a resolution of 3 Mpx or above.

Implications

Strategy Analytics forecasts that revenue from LED camera flash will grow at a compound average annual growth rate of 87% for the period 2004–2009. The decline in the existing display and keypad backlighting segments will force LED suppliers to revise their approach to the handset market. Strategy Analytics believes that consolidation is likely to occur, particularly among manufacturers of lower-end products for the keypad market. Market leaders will now need to realign themselves to ongoing changes in market requirements. Most importantly, suppliers will need to consider how to address the camera flash market, where the requirements of high illuminance, high efficacy, and appropriate thermal management offer considerable challenges, and many opportunities.

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LED SUPPLIERS

Agilent components group is now Avago Technologies

The business units that formerly comprised the semiconductor products group of Agilent Technologies, including one of the largest LED businesses in the world, will now be known as Avago Technologies. The company, based in San Jose, California, was launched on December 1 as the world's largest privately held independent semiconductor company.

Agilent has now completely divested its LED businesses, which have a legacy dating back around 40 years. In August 2005, Agilent announced its plans to sell off its semiconductor products group, and also to sell its stake in Lumileds (see below).

The semiconductor products group, now relaunched as Avago, was sold to two private equity companies – Kohlberg Kravis Roberts & Co. (KKR) of New York City, and Silver Lake Partners of Menlo Park, California – for $2.66 billion.

Interestingly, KKR owns a majority share in the Zumtobel Group, and is therefore linked to the Lexedis Lighting joint venture between Toyoda Gosei and Zumtobel's subsidiary, TridonicAtco (page 3). Despite this link, it seems unlikely that Lexedis will have much interest in gaining access to Avago's capabilities.

With an LED legacy dating back several decades to its time as part of Hewlett-Packard, Agilent Technologies was until quite recently the largest manufacturer of LEDs in the world. Avago ranks itself as the third largest global supplier of visible LEDs, as well as the number one supplier of blue LEDs for mobile appliances and of red and amber LEDs for electronic signs and signals.

Avago's LED business is based in Malaysia. The company does not make visible-LED chips, but a spokesperson said that "Lumileds will remain as a key strategic supplier for Avago". Avago's IP position is unclear, but the company is no longer included in the patent cross-licensing agreement between Nichia and Lumileds.

Philips completes acquisition of Lumileds Lighting

High-power LED specialist Lumileds Lighting is now officially part of Philips Electronics after Agilent Technologies completed the sale of its 47% stake in the high-power LED maker for approximately $950 million, plus repayment of $50 million of debt from Lumileds. For more details and analysis, see "Philips takes control of LED maker Lumileds Lighting".

Now that the acquisition is complete, Philips says it will focus on growing the Lumileds business and developing wider applications for high-power LED lighting. The company estimates that Lumileds will grow its revenues at a minimum of 25% a year, and will generate 5% of Philips' lighting sales.

Theo van Deursen, the CEO of Philips Lighting, said that the company now has a goal to achieve minimum revenue growth in its lighting division of 6% a year. "The level you've seen over the last few quarters was 5% in our conventional lighting business, and Lumileds adds another per cent. So, 6% for us would be the minimum target," said van Deursen in the webcast of a company presentation for analysts.


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Delegates highlight required improvements in LED lighting

Intertech's annual LEDs event took place in San Diego in October. Subjects ranged from standards and infrastructure for solid-state lighting to plant growth. **Tim Whitaker** reports.

In his plenary talk at LEDs 2005, Chips Chipalkatti, who runs the corporate innovation management group at Osram Sylvania, focused on the need to develop appropriate infrastructure for solid-state lighting (SSL). "Five years ago our industry thought we would conquer the world – quite frankly, we have not done that yet," he said. "The reason for this limited penetration is not due to efficacy [lumens per watt] or lumen output or heat – it's due to the lack of infrastructure."

There is a strong argument to suggest that building replacement light bulbs using LEDs is the wrong approach. For example, Edison bulbs are not designed to allow heat to go back into the socket, but thermal management is a key requirement for LEDs. "We have all these great LED and OLED technologies – why do we try to squeeze them into Edison sockets?" asked Chipalkatti.

Several approaches are required, one of which is the need for open-source access to technology, avoiding IP issues that could hinder development. The input of industry-wide bodies is also required. Many are active in this field, but, asked Chipalkatti, "Can this effort be focused onto creating a meaningful, standard infrastructure to leverage the advantages of solid-state lighting without the burden of legacy constraints?"

In a later talk, Bill Kennedy of Toyoda Gosei returned to a similar theme. Among the points Kennedy raised was the need to develop a metric to either augment or replace the color rendering index (CRI) – perhaps with the color quality index for LEDs, which is under discussion within NEMA's SSL group. Also, there is no consensus on how to measure the properties of a blue LED, so it is difficult to see how the industry can move forward to define standard white LED illuminants.

"With LEDs we have reached an opportunity for a new paradigm in lighting," said Kennedy, "yet we are ill prepared to realize their true impact in our products, designs and everyday life."

Lighting progress

According to Jan-Willem Andriesse, senior product manager for solid-state lighting at Philips, the biggest hurdle in Europe for using LEDs in general lighting is the quality of white light, while in China and the US the biggest issue is the total cost of ownership. The industry, he said, is in a period of focusing on projects and on customized and special lighting (figure 1), and is still several years away from the general lighting mass market.

"Five years ago our industry thought we would conquer the world – quite frankly, we have not done that yet."

CHIPS CHIPALKATTI, OSRAM SYLVANIA

Among the many areas that need to be addressed ("technology dissatisfiers" as Andriesse labeled them) are the following:

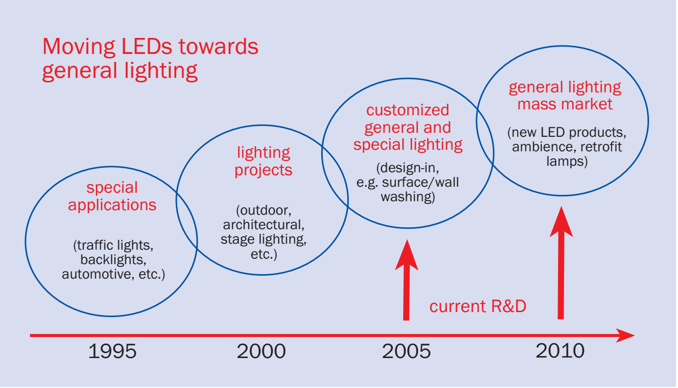


Fig. 1. The SSL industry is in a period of focusing on customized and special lighting, and is several years away from the general lighting mass market. (Courtesy of Jan-Willem Andriesse, Philips Lighting.)

- Although LED makers are breaking efficiency records, they are not breaking production control records, and more reproducible performance in quantity is required.
- Packaging should be improved, with lead-free solders, encapsulants that are stable over time, and a high level of reliability. Thermal issues also need attention.
- The flux per package is five times too small for spotlighting.
- The system lifetime is much less than the LED lifetime.
- The system cost per lumen is five to 10 times higher than it should be.
- Achieving color consistency requires stringent binning solutions at the system level.
- There is a lack of standards, for example in the area of CRI.
- There are many control and connectivity issues, stemming from the fact that "no LED is equal".

"The industry is still in its early stages," said Andriesse. "LED technology is moving forward rapidly, but system efficiency is still too low and the technology is still too expensive." Philips' view is that at present a modular approach is essential to deliver quality and reliability in the system.

Markets

Jagdish Rebello of iSuppli and Asif Anwar of Strategy Analytics gave different viewpoints of the status of the LED market. Rebello said that the total market for high-brightness (100s of millicandelas) and ultra-high-brightness (10s of candelas) LEDs was $2.78 billion in 2004 and

HB and UHB LED market in 2004

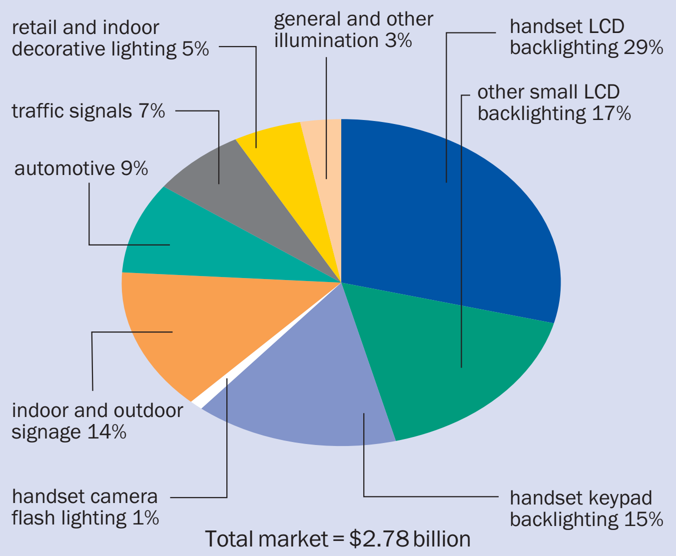


Fig. 2. LCD backlighting in handsets and other small devices was the major application for high-brightness and ultra-high-brightness LEDs in 2004. (Courtesy of Jagdish Rebello, iSuppli.)

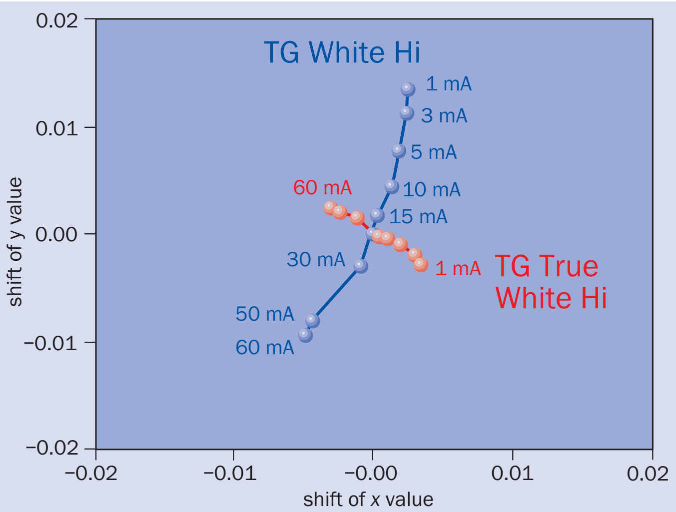


Fig. 3. Shift of white (*x, y*) coordinates, relative to values at 20 mA. Combined with 100% blue-die characterization, the barium ortho-silicate phosphor developed by Toyoda Gosei results in stable and consistent white performance in the company's TG White Hi device. The most stable white is achieved by combining purple LEDs with RGB phosphor (TG True White Hi). (Courtesy of Bill Kennedy.)

grew by 45% year on year, with the primary driver being LCD and keypad backlighting in mobile phones (figure 2).

As Anwar pointed out, these markets are close to being commodities, while camera flash represents a growth opportunity. "Megapixel camera phones are the sweet spot for flash LEDs," said Anwar. Strategy Analytics' numbers for the total LED market were $5.74 billion, of which 64% was high-brightness (HB) LEDs.

Other key markets for HB-LEDs, said Anwar, are automotive applications such as forward lighting; flat-panel TVs, in which LEDs are the backlight for LCD screens; and SSL or general illumination.

For ultra-high brightness (UHB) LEDs, Rebello said that several things need to happen. "This is a fragmented market without a single dominant driver," he said. "Companies need to work with OEMs to develop applications for the future." One target will be high-double-digit percentage reductions in the average selling prices for UHB devices. Also, additional production capacity for UHB-LEDs will be required.

LED manufacturers

Japanese LED suppliers such as Nichia, Toyoda Gosei and Rohm Electronics were prominent at LEDs 2005. Nichia's Drake Stalions focused on the company's Rigel 0.5 W and 1 W devices, as well as on the newly developed 200 lm and 400 lm Kirameki devices (see "Nichia unveils 200 lm and 400 lm Kirameki LED devices", p11).

The main approaches to producing white light with phosphor conversion are either to combine a blue-LED chip with a yellow-emitting phosphor, or to combine a near-UV chip with an RGB-emitting phosphor. Toyoda Gosei employs both of these approaches: its True White LED combines an RGB phosphor with a "purple" LED emitting at around 390 nm. Bill Kennedy said that Toyoda Gosei is the biggest producer of such near-UV LED chips.

Toyoda Gosei has also developed a yellow-emitting phosphor as a replacement for the commonly used yttrium aluminum garnet doped with cerium (YAG:Ce). YAG:Ce suffers from several problems such as a narrow excitation spectrum, and the white-LED properties tend to be very sensitive to the blue-LED pump wavelength.

The barium ortho-silicate (BOS) materials developed by Toyoda Gosei to replace YAG are alkaline-earth ortho-silicates activated with europium (where the alkaline earth metals could be barium, calcium and/or strontium). Kennedy said that, in combination with 100% die testing, the blue chip plus BOS approach produces a "very stable and consistent white result" (figure 3).

Camera flash and torches

Flash units for cameras in mobile phones are one of the key emerging markets for high-power LEDs. However, most of today's camera flash units use low-power LED arrays of three to five chips, which do not provide good functionality. "These support low-resolution cameras [less than one megapixel] at arm's length," said Tom Jory of eLite Optoelectronics, a fabless LED supplier that focuses on high-power chips for camera flash and other markets.

Although xenon flash units, which are used for all other cameras, perform much better than LEDs, the gap is closing. And, explained Jory, LEDs have many advantages, including small size, simple drive circuitry, zero charge time, and the option for continuous operation (torch mode).

In fact, LED torches are "booming", said Jory. "Miners in China are required by government mandate to use LED headlights," he said. "Also, LED torches are being touted as a key feature of mobile phones sold in third-world regions."

Optics

Chuck Milligan of Heptagon described compact solutions for LED beam shaping. "The industry needs complete solutions, including optics," said Milligan. "However, optics has failed to keep pace with the semiconductor guys."

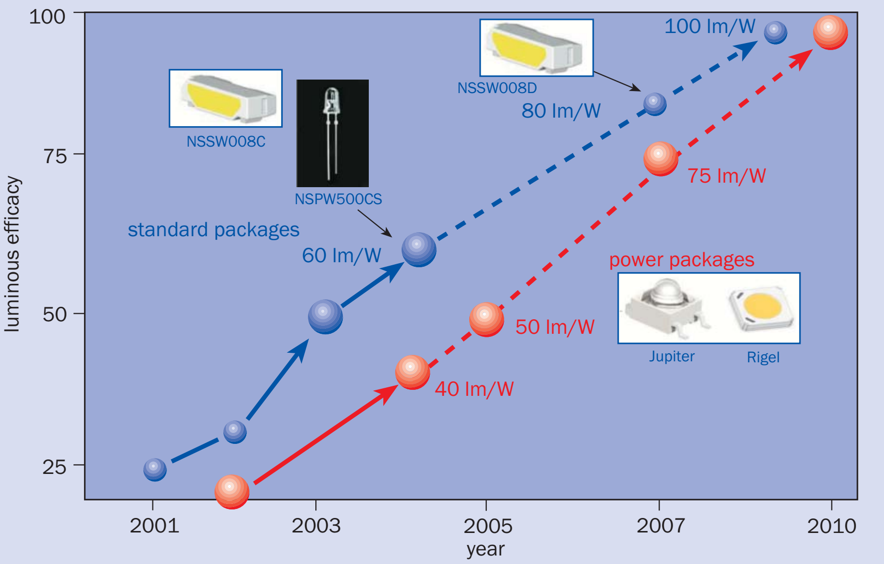
Micro-optics is an important complement to LED technology,

Nichia unveils 200 lm and 400 lm Kirameki LED devices

With its competitors capturing market share in the high-power-LED segment, it sometimes seems that Nichia is standing still in this area. However, this misapprehension was dispelled during the company's presentation at LEDs 2005. As well as producing the 0.5 W and 1 W Rigel series, Nichia has developed 5.5 W and 11 W devices, under the name of Kirameki, that have a luminous flux of 200 lm and 400 lm, respectively.

Drake Stalions, sales manager with Nichia America, described the company's Rigel series of power LEDs, which target lighting and other applications. The mid-power Rigel is a 150 mA, 0.5 W device in a ceramic package measuring 3.5 × 3.5 × 0.8 mm. One of the key features of this product, explained Stalions, is that the efficacy does not fall dramatically for warmer-white devices. Cool-white products (4600–9000 K) have an efficacy of 38 lm/W and a luminous flux of 20 lm, while the figures for the warm-white incandescent-equivalent (2800 K) device are 31 lm/W and 17 lm. Devices corresponding to cool fluorescent (4200 K) and warm-white fluorescent (3500 K) are also available, with intermediate flux and efficacy values.

Later this year Nichia will start sampling its 1 W Power Rigel, which has a luminous flux of 40 lm. The device draws 350 mA of current and has a small-footprint, low-profile package measuring 4.5 × 4.5 × 1.3 mm. Production will commence next year, at which point Stalions expects it to become the most cost-effective power white LED available on the market.



Nichia's luminous efficacy roadmap heads towards 100 lm/W. (Courtesy of Drake Stalions.)

Kirameki provides 400 lm for automotive
Stalions also described the company's new Kirameki device, developed for the automotive forward-lighting market. Two variants of Kirameki were discussed: a 5.5 W device with a flux of 200 lm, and an 11 W device with a flux of 400 lm. The packages measure 14 × 9 × 5.6 mm and contain multiple chips. Both devices operate at 700 mA and produce warm-white light at 4300 K – the desired white color for automotive forward lighting.

Another critical feature for this application, demonstrated by Kirameki, is that both the package and the die should have a very small optical area to achieve the required beam pattern with multiple devices.

The devices have an efficacy of 36 lm/W and will operate within the temperature range specified for automotive applications of –40 to +105 °C.

The maximum junction temperature for the devices is 150 °C. Both packages have an extremely low thermal resistance: 6 °C/W for the 5.5 W device and 3 °C/W for the 11 W device. Because of these values, the devices are not suitable for reflow soldering and must be mechanically mounted.

Samples have been sent out to several of Nichia's customers, and the company is awaiting feedback before finalizing the device specifications. Stalions said that the Kirameki are likely to be available for use in automotive applications by 2007.

following the same path of improved performance in smaller packages at lower cost. Conventional optical approaches with primary and secondary optics are not optimal, while custom-designed micro-optical elements have small dimensions and can be attached to the LED package using replicated mounting pins. The next stage will be to integrate the micro-optical function directly onto the LED wafer before dicing.

Heptagon is manufacturing micro-optical structures on 6 inch glass wafers and expects to move to 8 inch substrates soon, which will increase competitiveness with plastic components. While micro-optics are being used in several types of consumer products, Milligan says that "take-up in the LED market has not been as quick as we would have liked, although we expect this to pick up in the next couple of quarters". These structures are expected to drive better LED performance in applications including LED flash in camera phones, LCD backlighting, LED-based projection, and automotive and general illumination.

Projection
Two separate talks discussed projection applications. Several companies have already launched commercial mini-projectors using LED sources. Other applications include spotlights for cameras, architectural and decorative lighting, and automotive head-up displays and headlamps. The traditional approach for projectors is to use a white-light source combined with a color wheel, but this can be eliminated using red, green and blue LED light sources.

Hubert Ott of Osram Opto Semiconductors explained the importance of conserving étendue in a projection system, which in turn requires the correct choice of optics and a high-luminance light source. Osram's Ostar LED makes use of the company's thin-film technology in which the LED chip is essentially a surface emitter and does not emit from the chip sides. This maximizes the luminance, and makes the chip area scalable at constant efficiency. Ott said that the Ostar has achieved

(a) Yokohama Electron unveiled its new Ninja high-power device containing seven 1 × 1 mm^2 chips supplied by UEC. (b) ROHM Electronics booth. (c) Mike Miskin and Stewart Hough from Lynk Labs, who demonstrated their C^3LED driver technology. (d) Test and measurement specialists Labsphere. (e) Barry Williams and Rachel Cory demonstrate some of Nichia's LED products. (f) Osram Opto Semiconductors demonstrated a projection system using red, green and blue LEDs. (g) Optics manufacturer Carclo Technical Plastics. (h) Measurement equipment supplier Instrument Systems. (i) Sales and technical team from NYE Optical Products. (j) Hernan de Guzman and Alex Mednik of Supertex. (k) American Bright showcased its 3 W Novabrite LED system. Images a, f, k – copyright Cabot Media Ltd 2005. All other images by kind permission of Sarah Kottritsch of Sarah Jane Photography (sarahjanephotography@tiscali.co.uk).

Fig. 4. Red and green solar-powered LED signal lights are widely used in the marine environment – for channel, harbor and hazard lighting. The next big market for solar-powered LEDs is likely to be edge lighting on road signs. (Courtesy of Dave Green, Carmanah Technologies.)

a white-light output of 160 lm at 6.5 W and 210 lm at 10 W, and that further progress will be announced by the end of the year.

Sidney Chu of Cotco discussed the brightness requirements for LEDs in projection applications. For a handheld projector with a 7 inch display, the on-screen brightness requirement of 250 nits (candela per meter square) means that the projector must produce 12 lm, which in turn means the light engine must produce 120 lm, assuming 10% efficiency. For mini-projectors providing 20 inch displays, the requirement is 100 lm (or 1000 lm for the light engine), while 600 lm is required for rear-projection televisions.

Solar-powered lighting

Dave Green, the chairman of Carmanah Technologies, described the tremendous range of off-grid solar-powered LED lighting opportunities. "LEDs and solar power are uniquely complementary," he said. "Both are low-voltage DC devices. Low-cost high-performance microprocessors provide intelligent control, thanks to the computer industry; and DC–DC converters are now 95% efficient at low voltage, thanks to the cell phone industry." Solar-powered LED lights can be placed anywhere without external wiring or dependence on the grid, and provide secure and distributed power, added Green.

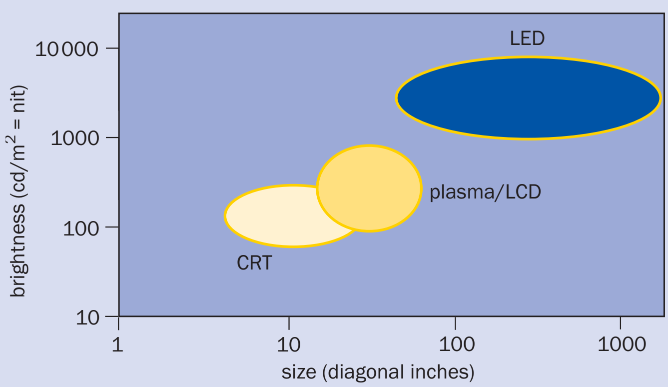
The biggest solar-powered LED application at present, selling millions of units a year, is the garden light. The oldest application is the marine market for channel, harbor and hazard lighting. "It's a matter of time for all marine installations to be LED," said Green, adding that size, cost and maintenance frequency of marine lights are all drastically reduced when using LEDs. Other key markets are aviation and roadways; the cost of digging up a sidewalk to install power cables for a roadway signal can often exceed the cost of a solar-powered LED fixture.

The above markets (except for garden lights) usually require colored lighting for signaling applications, where LEDs offer clear advantages. "White LEDs are not as convincingly superior to white fluorescent lighting," said Green. Even so, Carmanah has been active in installing white LED lighting in bus stops (see http://ledsmagazine.com/articles/news/2/9/26), and the "next big market" is likely to be edge lighting on road signs and advertising signs (figure 4).

General illumination is still at an early stage, although solar-powered lighting can be found in streets and parks. Green expects much innovation in this area, particularly in conjunction with security cameras. The developing world shows the greatest potential, with solar-powered lighting set to replace costly and inefficient kerosene lanterns. "Solar-LED is a leap-frog technology, like the cell phone," said Green. "It allows users to skip the grid-connected incandescent step." (See "White-light LED home systems benefit India's remote villages" on p17.)

In summary, Green said that solar-powered lighting provides exceptional economics: lower up-front capital costs, minimal installation costs, almost no maintenance costs, and no ongoing energy costs. →

LED displays in integrated networks



LED screens are best used when integrated with other display technologies. (Courtesy of Tony Turiello, Lighthouse Technologies.)

To attract advertisers, a digital signage network should have extensive coverage to reach the largest possible audience, and this means integrating many different display technologies. "LED systems will not eliminate other competing technologies but will complement them in integrated environments," said Tony Turiello of display manufacturer Lighthouse Technologies. "LEDs are most desirable in high-ambient-lighting conditions (indoor atria) or as the flagship display system in an integrated network. However, LEDs are the only solution outdoors." Content is then managed for the appropriate display, which often means lower-resolution content for LED displays and higher-resolution content for other displays.

Drivers and AC-LEDs

Several options exist for powering LEDs from AC line voltage. As Alex Mednik from Supertex discussed, one option is to use a switch-mode power supply to step down the voltage from 120/240 V AC to an output of a few volts DC. Low harmonics and a high power factor are required for most applications, and phase-control dimming is often desired. Also, a high mean time between failures at elevated temperature is needed to match the service life of the LEDs, and this means eliminating electrolytic capacitors.

Another option is to develop LEDs that can be driven by an AC supply without the need for power converters. III-N Technology has developed a technique (see US patent number 6,957,899) to build strings of series-connected micro-LEDs on a single semiconductor wafer. In each AC-LED device there are two strings, each with multiple emitters, which are connected in different directions: one string is illuminated during the positive half of the AC cycle, the other during the negative half. In the words of the patent, "the arrays are alternately energized and de-energized at the frequency of the AC power source, and thus the single-chip integrated LED always appears to be energized". Hongxing Jiang of III-N Technology was able to demonstrate the AC-LED by inserting the pins of a 5 mm LED directly into a power source.

Lynk Labs has developed an alternative AC-LED technology that uses existing dies rather than a chip-level multiple-die approach. "The mini-world of electronic products is a 'DC world' but the macro-world of lighting is an 'AC world'," said Stewart Hough, Lynk Labs' vice-president of business development, explaining that system solutions are required that pull together many critical elements.

Lynk Labs has developed capacitive current control (C^3LED) technology, which combines reversed opposing dies with a capacitor. Compared with using the same dies in a DC-driven resistor-based circuit, the C^3LED approach provides higher brightness at the same power (or alternatively uses lower power at the same brightness).

Silicones for packaging

One factor that determines the lifetime and reliability of HB-LEDs is the choice of encapsulation material, and many manufacturers are now using silicones supplied by companies such as Nye Optical Products, GE, NuSil and Dow Corning. Representing the latter, Maneesh Bahadur described the key advantages of silicones over organic materials. "Optically transparent silicones are resistant to blue light and high-flux white light, and provide increased stability and reliability over time," he said. They also provide excellent thermal stability, enabling them to be used with lead-free solder reflow processes that require higher processing temperatures than traditional lead-based solders. When asked why not everyone uses silicones for encapsulation, Bahadur replied: "Cost, and a lack of exposure to silicones in the LED industry." Silicones can also replace epoxy for LED die attach, while harder resins can be used for moldable optical parts such as lenses.

3D packages from Lednium provide wide-angle sources

An Australian company, Lednium, has developed a packaging technology to produce a wide-angle distribution for solid-state lighting, and has teamed with Optek to market its products.

Lednium, an LED technology company based in Melbourne, Australia, has developed what is described as the world's first three-dimensional LED platform for white, monocolor and mixed-color LED arrays. Products include a multichip geodesic-dome-shaped 10 W LED assembly that is available in white, blue, green, amber, red and other configurations such as RGB. The initial production of white devices yields 250 lm with a viewing angle of 120º (figure 1).

The company recently signed an agreement with US-based Optek Technology to jointly develop and market a series of products using the 3D packaging technology (see "Lednium and Optek target solid-state lighting", p16). Even more recently, Lednium signed a patent licensing agreement with Osram to license the German company's phosphor technology for manufacturing white LEDs.

The 3D products are assembled by mounting chips into cups, then the cups are placed into a dome-shaped lead frame. Lednium's unique packaging technology is repeatable in mass production, and it can accept all chip architectures, which means that it can benefit from future advances in chip technology.

LEDs Magazine spoke with John Montagnat, the senior development engineer at Lednium, to discuss details of the company's novel packaging approach.

What was the rationale for developing the 3D technology?
Our ultimate goal is general illumination, which we believe can be best achieved using LED arrays, and, more particularly, with arrays that are configured to have a "wide-angle-divergent" distribution of light [figure 2].

The 3D concept is, fairly logically, the reverse of the packaging industry trend of a few years ago. At that time LED packagers strove day and night to be able to boast of a light-intensity level that was greater than that of their competition – the more millicandela that could be claimed, the better.

However, the total amount of light was limited, and, to increase intensity, viewing angles became increasingly smaller. This meant that the LEDs available to the market became less useful for illumination. The trend was to make point sources, rather than to imitate the almost Lambertian distribution of an incandescent bulb or a fluorescent tube.

Realizing that it is unlikely that LEDs will ever be able to approximate a Lambertian source, we set out to push the boundaries of even light distribution within a hemisphere. A hemisphere is adequate since a significant percentage of traditional luminaires locate the light source on a surface (usually a ceiling), and this type of application does not require 360º light distribution.

Fig. 1. With a unique dome-shaped package, the 10 W Lednium LED produces 250 lm in white at a current of 1.05 A. Excluding leads, the package size is 33 × 33 mm, and the height is 8 mm.

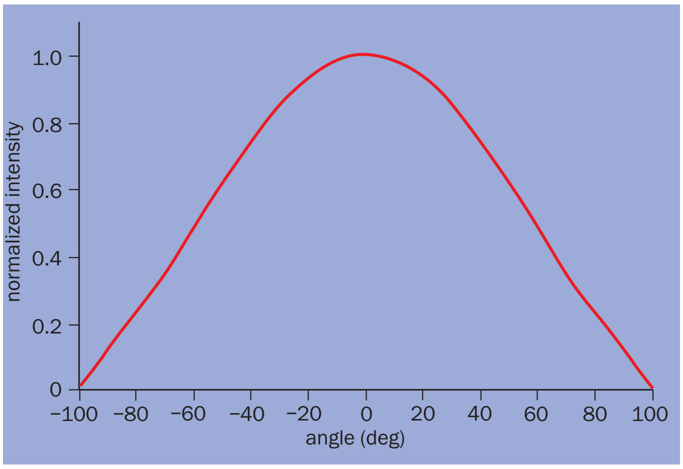


Fig. 2. The spatial intensity distribution of the 10 W Lednium array is extremely uniform and has a viewing angle (defined at half maximum intensity) of 120º.

Within the 3D package, LED chips are mounted inside cups, which are themselves placed into the preformed lead frame. Can you describe the manufacturing process?
The assembly process is automated using purpose-built machines that combine four different copper lead-frame [LF] arrays.

The first is an array of cups [LF 1] that is combined with a matching array of preformed insulation cut-outs and an array of ring contacts [LF 2]. The result is a composite array of cups, each of which has an "insulated ring" attached to its rim.

LED chips are attached into the cups and connected by wire bonds to the ring contact and to the copper cup if necessary. Phosphor is added in the case of white LEDs. This array has an epoxy package molded over each cup. After singulation from the array, each cup is now an operable packaged LED.

How is the final package assembled?

A preformed lead frame [LF 3] is introduced that contains through-holes in a raised, part-spherical dome. The holes are located to accept the molded cups [figure 3].

The lead frame is divided into three sections. After the cups are attached in the through-holes they are connected in three groups in a series/parallel arrangement by three ring contacts [LF 4]. This assembly is overmolded with epoxy material and enclosed in a two-piece aluminum housing [figure 4].

The lead frame allows any group of cups, or combination of groups of cups, to be controlled independently.

How is the thermal management of the package handled?

Thermal management is primarily handled by the copper lead frame. The thermal resistance from junction to board is only 5 ºC/W. The heat source, i.e. the chip, is mounted in a copper cup attached to a copper lead frame that extends outside the package.

The extensions are in the form of pins, which, when coupled to a metal-core PCB or the like, provide excellent thermal conduction.

In addition, these pins are clamped between the two halves of an outer package made from aluminum. The bottom surface of the package is thus used as a secondary thermal path.

Where is production carried out?

Production will initially be carried out in Malaysia, with all design and R&D projects directed from the Lednium headquarters in Melbourne, Australia. Lednium will manufacture all products to be marketed through the agreement with Optek.

We have no facilities to manufacture LED chips, but there are many potential suppliers of chips for us to choose from. At the moment we have an inventory of chips from the US, Taiwan and Japan.

The licensing agreement with Osram [see "Links"] allows us to use Osram IP to generate white light from any Lednium LED array. ●

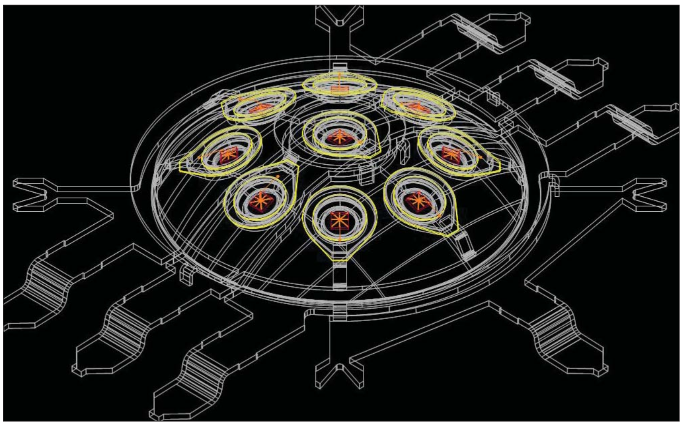


Fig. 3. After placing LED chips inside cups to create individual LED packages, these cups are positioned in a dome-shaped lead frame.

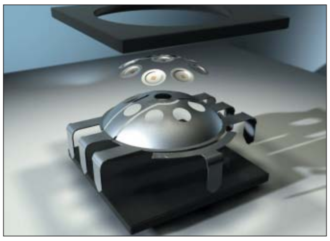


Fig. 4. Once the cups have been positioned in the through-holes of the dome-shaped lead frame and connected to three ring contacts, the assembly is overmolded with epoxy material and enclosed in a two-piece aluminum housing.

Links

Lednium: www.lednium.com
Optek: www.optekinc.com/products/vled.asp

On our website:
Osram and Lednium sign white LED license agreement
www.ledsmagazine.com/articles/news/2/11/21
Optek and Lednium form alliance to target solid-state lighting
www.ledsmagazine.com/articles/news/2/10/14

Lednium and Optek target solid-state lighting

Optek Technology, a visible LED manufacturer based in Carrollton, Texas, which is part of the TT Electronics group, has signed a joint R&D, manufacturing and marketing agreement with Lednium. The alliance combines the strengths of both companies to create what they expect will be a "significant presence" in the emerging solid-state lighting industry.

Optek says that it will develop a series of solid-state lighting products using 3D packaging technology developed by Lednium. The Optek Lednium Series includes the OVTL09LGAx series (figure 1) – a 10 W, nine-LED package available in white, blue, green, amber, and red, along with color combinations such as RGB.

The white device has a luminous flux of 250 lm and an on-axis intensity of 70 cd, with a 120° viewing angle that is common to this design. These characteristics are measured at a junction temperature of 25 ºC and an input current of 1.05 A.

Applications for the Optek Lednium Series include architectural and automotive lighting, aviation, display, entertainment, gaming and vending machines, marine, military, signs and signals, variable message signs and general illumination.

Optek established a Visible LED Business Unit in early 2005, and its product line includes industry-standard high-brightness and high-power LEDs. Optek Technology was acquired by TT Electronics plc, a global electronics company, in December 2003.

Optek and Lednium plan to jointly develop products at other wavelengths for markets that include medical and surveillance.

"This partnership is an ideal building-block for many value-added and customer-specific lighting assemblies for our automotive and industrial assemblies programs," said Richard Saffa, vice-president of Optek's Visible LED Business Unit. "Lednium brings a wealth of experience to the partnership, and its commitment to high standards has helped it achieve numerous awards."

LEDs MAGAZINE

White-light LED home systems benefit India's remote villages

Solar-powered white-LED lighting fixtures are having an enormous positive impact on the lives of villagers in the remote regions of Andhra Pradesh, in south-east India.

White-light LED technology is being used for the first time in the Indian state of Andhra Pradesh to provide low-cost home-lighting systems for remote tribal and *dalit* [1] habitations.

Small solar panels, or even manual power, can produce enough energy to keep the LED lights burning for hours. As well as enabling children to read and study, this will reduce the dependence on kerosene lanterns for lighting.

Thinksoft, a group of development experts, has helped to pioneer the introduction of white-light LED home-lighting systems for the benefit of the poor in India. "The initial response...has been extremely enthusiastic, and we are besieged in the villages by people clamoring for more," said Dr Vithal Rajan of Thinksoft.

Introducing solid-state lighting is expected to help alleviate some of the economic and environmental problems associated with energy and lighting in India (see "India's energy and lighting crunch", p18).

The installations have been carried out under an imaginative three-year program implemented by the Centre for Environment Concerns – a non-governmental organization (NGO) of Andhra Pradesh, and funded by the Indian government's Ministry of Tribal Welfare.

"So far we have installed around 350 LED home-lighting systems in as many poor and remote households," said Rajan. These are in a cluster of five villages of the Chenchu indigenous tribe, as well as a small group of *dalit* households, and a hamlet *(thanda)* of the formerly nomadic Lambada people, who are from the original stock that produced the gypsies of Europe.

White-light LEDs in the home will reduce people's dependence on kerosene, which has environmental and health implications.

Photovoltaic panels provide energy for the LED lighting systems.

White light sources

Around 200 of the LED lights were a gift from Prof. Dave Irvine-Halliday, the Canadian president of the Light Up the World Foundation (LUTW). Each of these lamps uses a single 1 W white-light LED.

The rest of the lights were designed by V C Srinivasan, a retired engineer who is team leader of the local research group. These lamps have a cluster of six 0.2 W white-light LEDs, supplied by Kwality Photonics of Hyderabad, which is owned by scientist-enthusiast Dr Vijay Gupta.

"Right now the only power source for the LED lighting systems remains solar photovoltaic [PV] panels, either 5 W or 3 W in size, both polycrystalline and amorphous," said Rajan. "However, we have started experiments to design suitable dynamos, which can generate electricity through human pedal or bullock-driven systems. The panels charge 12 V or 6 V sealed lead-acid batteries."

Any problems with the lighting systems have been minor and easily corrected. These include poorly applied insulation tape, wrongly positioned PV panels, short lengths of wiring, and the poor quality of some locally made switches.

The project aims to create an LED home-lighting system that costs around 1500 rupees (about £19 or $33), which the poor can buy on hire purchase from tribal or *dalit* co-operatives and own after paying 18 monthly installments. The installments will be no higher than the cost of kerosene.

Local organizations

The LUTW became involved in the project when C R Gayathri, special chief secretary and director-general of the Environment Protection Training and Research Institute (EPTRI)[2], invited Prof. Irvine-Halliday to sign a technology-sharing memorandum of understanding. Prof. Irvine-Halliday met with India's president, Dr Abdul Kalam, and the prime minister, Dr Manmohan Singh, who both asked that the lighting systems should be introduced as rapidly as possible in India's remote villages. LUTW is already helping several other countries in the developing world, like Nepal, to benefit from the technology.

A consortium has been formed in Hyderabad, the capital city of Andhra Pradesh, to indigenize the fast-developing technology and reduce costs. The US-based Satyam Foundation has linked with

EPTRI and Mahila Sanatkar of the Confederation of Voluntary Organisations (COVA) – the city's leading NGO. COVA works for communal harmony through grassroots development by offering management and marketing support to self-help groups of Muslim and Hindu women.

These groups will secure sustainable livelihoods by assembling the lighting systems and improving on present models. The low-cost, locally manufactured systems should enable tribal and *dalit* co-operatives to purchase them for members without needing a subsidy.

Future directions

Although progress has been made, several major problems still need to be addressed. One is to connect with lead manufacturers to locate suitable LEDs. "None of the major LED manufacturers is involved in the project as yet, but we hope they will take an interest," said Rajan.

The participants need to learn on the ground the key issues of system integration. To ensure that lighting is effective, they will have to acquire suitable charge drivers or microcontrollers to maintain constant luminosity over several hours of use while not wasting battery output through resistive losses. Further work will be required to arrive at the best optics design, or to use diffractive optical elements, to focus light for ambient or task use.

Since energy is at a premium, dimming devices will have to be installed to save energy and provide night lights. The program will also aim to create alternatives to expensive PV panels, such as manual power. Finally, it is planned to develop a testing and field-research center as part of the program. ●

India's energy and lighting crunch

As India struggles to modernize and boost the development of its citizens, it faces some enormous problems:

- Around 40 000 remote tribal villages in India will never be connected to the national grid for economic and ecological reasons. Hence 50 million tribal people can only have access to kerosene lanterns.
- According to reliable estimates, half the rural population, even in "electrified" villages, have no access to home electric lighting. That is, around 100 million households have only kerosene lanterns.
- The *Human Development Report* (commissioned by the United Nations Development Programme) estimates that 500 000 women in rural India die every year of respiratory diseases caused by kerosene and similar materials.
- The report suggests that stagnant illiteracy in rural areas, especially in girls, is directly attributable to a lack of electric lighting, and this fact is one of the greatest impediments to development.
- If 100 million households use at least one kerosene lantern, they burn around 6 billion litres of kerosene a year for lighting, causing environmental pollution and contributing to climate change.
- The drain on the Indian exchequer to maintain subsidies on kerosene is considerable.
- Extending the national grid would not solve the economic or ecological problems, for India's base load is met by thermal stations that burn high-ash-content coal.

Links

Light Up the World Foundation: www.lutw.org

On our website:
Energy Efficiency and Sustainability
www.ledsmagazine.com/articles/features/1/5/11/1

Share your experiences
LEDs Magazine would be pleased to hear from any companies or organizations involved in similar projects around the world.

Contact information

Anyone interested in assisting the program by providing expertise or hardware should contact Vithal Rajan (e-mail: Hyd1_vithal2@sancharnet.in or vithalrajan@hotmail.com; tel.: +91 40 2344 9193).

Endnotes

[1] *Dalit* means a person belonging to the *dal* (community). This is a new, dignified way by which castes formerly termed "untouchables," among the poorest and most oppressed of people, now identify themselves.

[2] The Environment Protection Training and Research Institute is an autonomous agency set up by the Indian government around 15 years ago with a national mandate. It is always headed by a senior government official and has large research and outreach facilities.

LEDs MAGAZINE

The 5 mm package versus the power LED: not a light choice for the luminaire designer

Although the design of lighting fixtures tends to favor power LEDs, there is a still a strong case for using the good old 5 mm package, writes **Jeff Bisberg** of AlbEO Technologies Inc.

As solid-state lighting (SSL) technologies continue to mature, many obstacles still remain, impeding the successful introduction and commercialization of products. The dream of using LEDs to replace millions of incandescent lights has led many in the industry to select high-output power-LED packages as the light source for their solid-state luminaire designs. Unfortunately, power LEDs create substantial thermal issues for the luminaire designer and often lead to compromised efficiency and performance of the lighting system.

Although power-LED devices play a key part in the roll-out of SSL technology, the author believes that for LED lighting to ultimately succeed we must realize that the ideal form factor for LED lighting technologies may not be the same as that of the traditional incandescent light bulb. Form factor optimization is illustrated in fluorescent lighting (as well as in many other technologies), where the ideal shape is a tube; only after many years was fluorescent twisted to meet the form factor demands of incandescent.

Beyond form factor optimization, LED lighting also brings a new paradigm shift – from the importance of the replaceable bulb to the importance of the fixture. With LED lifetimes capable of spanning generations, the lighting designer must look at the luminaire as a permanent electro-optical system that requires minimal or no maintenance. By removing the constraint of the replaceable incandescent bulb, new high-output 5 mm LEDs simplify fixture design, reduce costs, and result in a product that meets consumers' lighting needs economically.

This article will explore, from the luminaire designer's point of view, the factors that drive choosing a power-LED package or a 5 mm or similar small-die package for applications that do not require a traditional incandescent light bulb form factor.

AlbEO's Repleo lighting system contains 810 white LEDs in 5mm packages. It is designed for retrofitting stairwells and corridors.

Efficiency or output

There are issues at the die level, the lamp level, and the luminaire level that all need to be considered when determining the ideal LED light source for a given application.

At the die level there are three goals: to convert the electrons to photons, to get the photons out as efficiently as possible, and to maximize light output. Several factors make these goals difficult to achieve simultaneously. The desire to maximize efficiency drives the LED designer to choose small dies that have a high surface area to volume ratio for good light extraction. On the other hand, with die current-densities limited to about 20 A/cm^2, maximizing light output favors big dies that can handle more current. But these larger dies sacrifice efficiency because they have higher resistive losses, higher extraction losses, and higher internal losses.

Data on the reduction in efficiency with increasing die size are difficult to find from most LED vendors, and are further clouded by inconsistent and unpublished test conditions. However, it is clear that the old argument that the maximum output achievable from a 5 mm LED was 1 lm is now history, and new 2–4 lm devices are commonly available, with even higher outputs on the near horizon. →

Table 1. Comparisons for luminaire design

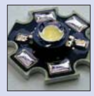
	5mm LED 	Power LED 
LED die		
Resistive losses	√	
Internal losses	√	
Total light output		√
Overall efficiency	√	
LED lamp		
Package thermal design		√
Total current/LED		√
Typical efficiency	√	
Multisourced	√	
Lumens per unit area		√
Choice of wavelengths	√	
Choice of viewing angles	√	
Light Fixture		
Minimum heat-sinking requirements	√	
Simple drive circuit	√	
Simple PCB design	√	
Redundancy	√	
Bulb replacement form factor		√

Table 2. Comparison of cost factors

	Small-die LED 	Power LED 
Drive circuitry	low	medium to high
Heat sinking	low	high
Lensing	low	medium to high
PCB	low	high (metal core)
LED mounting	moderate	moderate

The problem with heat

At the level of the LED lamp, the principal design considerations are to extract heat and light. Unlike incandescent lighting technologies, which require heat to function, the semiconductor materials that are used to make LED light abhor high temperatures. Excessive heating has two major negative effects on an LED: reduced efficiency and reduced lifetime.

A typical 5 mm LED package produces approximately 120 mW of heat, while for a typical power LED the amount is 1–5 W, or 8–40 times more than the 5 mm package. Not only does the power LED's requirement for extra heat dissipation need special packaging, it also means that the light fixture has to use large heat sinks, which change the form of the luminaire.

Even with special packaging, the power LED operates at a substantially higher temperature than the 5 mm device, resulting in reduced efficiency. Ironically, the need for large heat sinks significantly limits the packing density that can be achieved using power LEDs, and this has the effect of reducing the total lumen flux from an equivalent-sized luminaire.

Another factor to be considered by the LED luminaire designer is management of the supply chain. We believe that any critical component in a high-volume product, such as an LED, should have at least three sources to ensure continuity of supply. The proprietary package designs of power LEDs make multisourcing difficult at best. In contrast, 5 mm LED sources are mostly interchangeable and are available from various sources in many colors and viewing angles. The author would support an industry-wide effort to standardize the power-LED package to provide luminaire designers with consistency and choice. This would help increase the adoption and drive down the cost of power-LED-based luminaires.

Designing the luminaire

At the luminaire level these issues come together and have a significant impact on the design of the LED light fixture. Luminaire surface area, lumen output, thermal dissipation, the area to be illuminated, illuminance levels, and drive circuitry are just a few inputs that control the selection of LED light source .

Surprisingly, size is not the major constraint in many luminaires. For example, a typical under-cabinet lighting fixture measures approximately 1 × 5 × 22 inches. This gives a surface area of over 110 square inches, which could vary by as much as 10–20%. With a very low packing density of two 5 mm LEDs per square inch, a total of 220 such LEDs could be incorporated.

Using 5.5 mm white LEDs with an output of 2.5 lm would provide a respectable total output of 550 lm, and this would jump to 770 lm at 3.5 lm per package. Considering that the fixture efficiency for LED-based luminaires is almost twice that of most incandescent or fluorescent fixtures, a 5 mm-based under-cabinet lighting solution would compete head to head in this application space.

AlbEO's Talea line of under-cabinet luminaires uses 30, 60, 90, or 120 LEDs and gives illuminance levels that equal or surpass those of many fluorescent fixtures. The company's newest product, Repleo, contains more than 800 5 mm LEDs and is designed to ease lighting retrofits of stairwells and corridors to meet the stringent new 10 foot-candle minimum lighting codes. Minimal heat sinking makes for a slim and efficient design.

Redundancy and reliability

Since customers will be paying a premium for an LED solution, reliability and lifetime will be critical to payback, and 5 mm LED packages can play a big role in improving both.

Using large numbers of 5 mm LEDs introduces a redundancy that has never been achieved before in conventional lighting systems. If one LED fails, the total light output is hardly changed (0.45% for a 220-LED fixture). A failure in a power-LED lighting solution for the same under-cabinet light could reduce output by as much as 20%.

Another benefit of an array of LEDs is the ability to drive at reduced current and greatly extend lifetime while reducing lumen depreciation. The reduction in drive current further increases the efficiency of the LED by reducing the heat load and operating temperature.

Drive circuitry plays a secondary role in the cost structure of most LED lighting systems. To get increased light levels from power LEDs, much higher drive currents are required. Drive circuits for high-power

LEDs are usually switching based and are typically sole-sourced ICs. These ICs may be less reliable than the actual LED, they cost more than the simple circuits used to drive 5 mm LEDs, and again they limit the flexibility of the supply chain.

"For LED lighting to ultimately succeed we must realize that the ideal form factor for LED lighting technologies may not be the same as that of the traditional incandescent light bulb."

Cost analysis

The choice of LED technology also has many cost implications. Unless the power LED can be sold at a much lower price in terms of dollars per lumen, the cost of the luminaire will be higher owing to the added complexity of the drive circuitry, heat sinking, lensing, and metal-core printed circuit board requirements (see table 2).

When comparing costs, care must be taken to measure the cost per lumen for the actual operating conditions, which includes thermal derating. For example, a derated 3 W, 90 lm power LED will need to cost much less than 29 × 5 mm LEDs with 2.5 lm output to compensate for the additional overheads that are associated with the power LED solution. This does not include the significant non-recurring expenditure that is involved in designing and modeling the power LED's thermal housing and drive circuitry.

This type of cost analysis can be applied to many types of fixture. The reader will mostly find that when we move away from the paradigm that an LED solution must be constrained to a traditional bulb form factor, arrays of low-power devices will provide cost-effective robust lighting solutions.

The desire for a drop-in replacement for the traditional incandescent lamp is strong and clearly favors power LEDs. However, steady improvements in the performance of the 5 mm LED has provided lighting designers with a wider range of colors, optics, and efficiency than any other package.

The development of the 5 mm LED's cousin, the surface-mount LED, to provide a greater variety of colors and viewing angles will further extend the desirability of the small-die LED product family.

Clearly, shifting away from the bulb paradigm gives the luminaire designer greater freedom. The small-die LED will play a key role in providing cost-effective, highly reliable products that meet the demanding requirements of the lighting industry. ●

About the author

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ConceptLED: concentrated dispersion of the light source

LED technology enables luminaire manufacturers to break free from the restraints of working with conventional lamps, say **Moisés Domingo** and **Julián San Miguel** of Indal Group.

In the general lighting sector, innovation has traditionally depended on the technological progress of lamps or light sources manufactured by the enormous multinational companies that control the market.

As an example, a reduction in the diameter of fluorescent lamps has resulted in several innovative designs and applications as part of the evolution towards smaller sizes and whiter light. This in turn has enabled the design of more compact and efficient luminaires.

Also, lamps are developed for an objective market that establishes the size and shape of optical systems, and these in turn define the luminaire geometry and volume.

Most luminaire makers cannot develop and manufacture their own lamps. As a result, the appearance of a new lamp is often considered sufficient grounds to develop a new, specific luminaire. Consequently, the innovation undertaken by many luminaire manufacturers depends, to a large extent, on the directions taken by the lamp manufacturers.

However, the determining factor for innovation within the general lighting sector may be quite different in the 21st century. The enormous evolution experienced in high-power LED technology over the last five years represents a small but intense source of light on the horizon for luminaire manufacturers. LED technology represents a hope for independence from the major lamp manufacturers, and offers unlimited possibilities in the creation, application and service of products.

Indal Group's ConceptLED luminaires designed for outdoor lighting contain 80 high-power, white Luxeon III LEDs from Lumileds.

Concentrated dispersion

The LED implies a radical change in a products' conception, in its technical characteristics, in its manufacturing methods, in its aesthetics, and in the way of offering a lighting solution to the customer.

LEDs provided the initial impetus for Indal Group to develop the ConceptLED luminaire, which fully exploits the design possibilities of LED technology in what we call "concentrated dispersion of the light source".

On the one hand "dispersion", because we move from an intense and localized light source for conventional lamps to a series of light sources distributed along a specific surface. On the other hand "concentrated", since light emission for each source is produced in a very small area.

Dispersion allows innovation in aesthetic and conceptual design, and enables the creation of new applications. Concentration enables a degree of control of light that is unattainable with conventional lamps, and which provides high energy-efficiency.

The determining factor for innovation in general lighting may be quite different in the 21st century.

ConceptLED results from an effort in applied research, because we are so convinced of the real possibilities of LEDs in lighting. It is the outcome of a coherent working procedure where technical and functional approaches run in parallel.

ConceptLED luminaires

The luminaires designed for outdoor lighting contain 80 high-power, white Luxeon III LEDs from Lumileds. The carefully designed optical system produces a lighting performance that doubles those values attained through the conventional reflector-plus-lamp configuration for a standard road installation.

The heat dissipation system guarantees a working temperature for the LEDs that extends their lifetime and decreases luminaire maintenance costs by a factor of 10, as compared to that of an equivalent luminaire with a white-light discharge lamp.

ConceptLED is Indal Group's first development to introduce in the streets the technology that will represent the innovation in lighting in the 21st century.

About the authors

Moisés Domingo and Julián San Miguel are with the R&D department of Indal Group (www.indal.es/iindex.html). Indal Group is the leading Spanish industrial group specialising in lighting, and the biggest exporter with a presence in over 45 countries.

LEDs MAGAZINE

Valeo employs LEDs in novel automotive lighting concepts

Hybrid xenon–LED headlamps and light guides for rear lighting are among the latest LED technologies developed by French automotive supplier Valeo, writes Tim Whitaker.

Valeo, a France-based industrial group and one of the world's top automotive suppliers, has more than a decade of experience in developing LED-based lighting technologies. Among its newer innovations are methods of creating a homogenous appearance for rear lighting, and a combined xenon–LED approach to front lighting.

For rear lighting Valeo has developed MicroOptic technology, which replaces standard optics (such as lenses and reflectors) with a light guide. "LEDs are a point source, and from a style point of view we want to move away from being able to see the individual pixels and have something more homogenous," said Jean-Paul Charret, core engineering director with Valeo Lighting Systems. This development is in response to feedback from Valeo's customers and from vehicle drivers. LEDs are chosen over bulbs as the light source owing to their small size and high brightness.

The light guide is typically a diffuser sheet or a light pipe. Light-guiding screens can be used as stop lights and turn indicators as well as tail lights. Charret says that rear combination lamps using a homogenous light-guiding screen have been demonstrated on the Renault Egeus concept car (figure 1) and are ready to go into production.

The same light-guiding effect has already been used on several cars in the center high-mounted stop lamp (CHMSL). A typical CHMSL might contain 12 or 16 red LEDs that are each visible. Cars such as the Renault Scenic and Opel Corsa feature Valeo's CHMSL technology, combining the light-guiding effect with only four LEDs.

Valeo showed vertical light pipes on the V360 vehicle demonstrator at the IAA International Motor Show in Frankfurt. Light pipes can be used to direct light to achieve the correct photometric pattern, and are suitable for all lighting functions.

Another Valeo rear-lighting technology is MonoLED, which seeks for cost reasons to replace existing light sources with a single LED. As well as requiring high-power LEDs, this technology also needs high-efficiency optics to provide sufficient light to enable all the required functionality. In this case, the LED is visible as a point source, similar to a bulb.

Fig. 1. The rear combination lamp on the Renault Egeus concept car employs Valeo's MicroOptic technology, which combines LEDs with a light-guide sheet to create a homogenous appearance.

Fig. 2. An example of a full-LED headlamp developed by Valeo.

Forward lighting

Like its competitors, Valeo is developing full-LED headlamps (figure 2) and has demonstrated these on several Renault concept cars, including the Fluence and the Egeus (see Links, p24). However, the company has also developed a hybrid technology, XLED, which combines a xenon lamp with LEDs. "Although LEDs are progressing rapidly, a powerful headlamp still requires a lot of LEDs," said Charret "We achieve at least xenon-level performance, and this requires so many LEDs that cost, while not prohibitive, is still pretty high." →

Forward-lighting functions

In addition to high- and low-beam functions, headlamps may offer several other front-lighting functions.

A dynamic bending light uses the mechanical movement of a xenon lamp to shift the entire beam pattern. A fixed bending (or cornering) light is switched either on or off. Both provide adaptive illumination on the roadway as the vehicle turns, to assist the driver. A progressive bending light, in which LEDs switch on one after the other, is midway in function between a dynamic bending light and a cornering light.

Motorway lighting provides additional lighting on the roadway for improved driver vision when the vehicle is travelling at high speed. Motorway lights are not permitted at the moment, but the regulations are expected to change in 2007.

In contrast, the daytime running light is a signal function that enables people in front to see the car approaching.

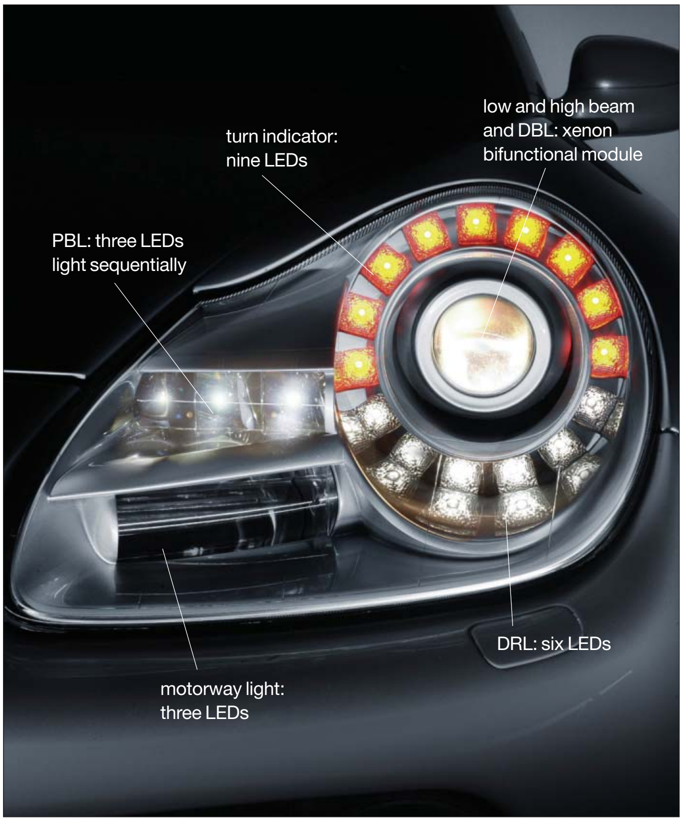

Fig. 3. Valeo's XLED headlamps include a xenon module that provides high- and low-beam functions and a dynamic bending light (DBL), while other functions are implemented using LEDs. These are a daytime running light (DRL), a motorway light, a progressive bending light (PBL), as well as a turn indicator.

Charret says that the main benefit of using LEDs in forward lighting is styling. Because the xenon lamp has a small lens, there is still enough space around it to design other headlamp functions using LEDs. "The XLED solution combines the high performance of xenon with the styling freedom provided by LEDs," said Charret. "It gives the best of both worlds at an affordable cost."

LEDs can also be used to add performance and functionality, for example in adaptive front lighting (see "Forward lighting functions"). In the XLED headlamp, LEDs provide a daytime-running-light function, a motorway light, a progressive bending light, and a turn indicator (figure 3).

XLED is viewed as a transitional approach that will be deployed while the industry waits for LED technology to improve sufficiently for full-LED headlamps to become affordable.

"A hybrid solution is likely to reach the market first," explained Charret. "We will see some full-LED headlamp solutions, but the cost will be still very high, and they will be limited to luxury models. However, a hybrid solution like XLED could see more widespread use in the near future."

XLED will still be more expensive than a conventional halogen headlamp, said Charret. "With LEDs we could have something that is cheaper in 10 years from now, but today we are far from that."

LED headlamps are still awaiting approval in Europe. "The current prediction is that regulations will be updated around the beginning of 2008," said Charret. The situation is different in the US, where LED headlamps are already allowed provided they meet photometric and other requirements. "I think there is a good chance that one US car will be on the market with a full-LED headlamp solution in 2007," predicted Charret.

Advantages and outlook

Charret believes LEDs offer two advantages that are important for both front and rear lighting: one is styling and design freedom, and the other is that the technology lasts for the lifetime of the vehicle.

Other advantages such as lower power consumption, reduced packaging depth, and a better driver response time for the stop function are also important for rear lighting. On the front side, there is again a packaging advantage but not to the same extent as for rear lighting. Similarly, power consumption is not as big an advantage, since the LEDs are not as efficient as xenon.

In addition to the obvious goal of reducing prices, LED makers have several other targets. "LEDs need to have a better tolerance to temperature," said Charret. "Variation of performance with temperature is still a big issue, and generally this requires the use of a large heat sink." For rear technology, the main focus is to reduce the cost so that it is almost at the same level as incandescent.

LEDs also need to become more efficient, and Charret believes that this will continue to improve. "Valeo began to use LEDs in CHMSLs more than 10 years ago," he said. "Considering how far we have come since then, it's clear to me that LEDs will continue to gain penetration in the market."

Links

Valeo: www.valeo.com

On our website:

Conceptual LED headlamps see around corners (Renault Valeo)
www.ledsmagazine.com/articles/news/1/9/6

Valeo supplies LED headlamps for the Renault Egeus
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LED lighting modules: taking the heat out of the situation

Managing temperatures using appropriate packaging materials is essential to ensure the reliability of high-power LED applications, explains **James Stratford** of Universal Science.

The appeal of using LEDs in lighting applications is growing rapidly. The numerous and significant benefits of using modules that incorporate a matrix of LEDs are being recognized by design engineers in several key industry sectors, including aerospace, architectural lighting, and the "golden egg" automotive market.

Attributes such as design flexibility, low power consumption, even and reliable light, and long lifetime distinguish LED modules from designs based on traditional filament lamps and fluorescent tubes. LEDs can also have knock-on benefits, such as greatly reducing the size and complexity of the module and simplifying the lens design.

A good example of some other benefits of LED lighting is demonstrated by an application in the cabin of a passenger aircraft. A retrofit LED unit that replaced a fluorescent-tube lighting module enabled finely controlled dimming and also provided mood lighting through the use of differently coloured LEDs.

Unilam insulated metal circuits for high-power LED mounting.

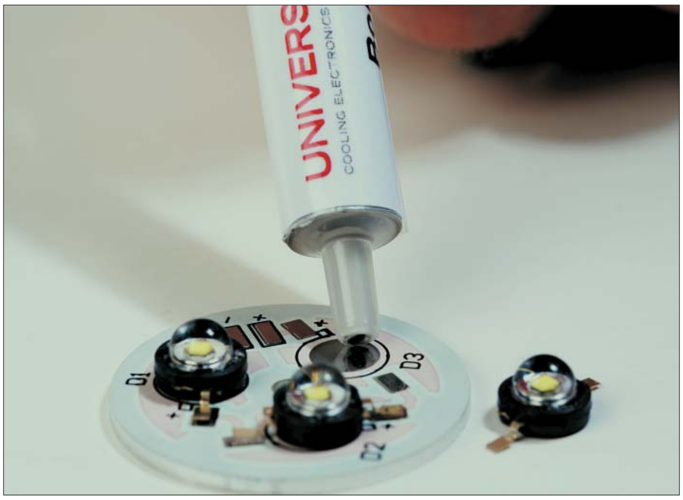
Thermal management

Perhaps the most challenging issue when realizing a module design that uses LEDs is to manage the temperature of individual device junctions during normal operation. If the considerable amount of heat produced by all the devices in a module is not managed correctly then the junction temperatures may reach a level where the LEDs' expected life is shortened and reliability is compromised (see Links).

LED modules typically comprise a matrix of many surface mount devices. These LEDs are soldered to an etched copper layer that provides the interconnects between the individual LEDs as well as other passive and active components that are required to complete the circuit. The small size of the LEDs and the close proximity with which they can be mounted means that designers have a huge amount of design freedom and can achieve complex lighting patterns with high levels of brightness.

The etched copper circuit is separated from a base plate – usually made of aluminum – by a thermally efficient, electrically isolating dielectric material. The characteristics and capabilities of the dielectric layer are key to the design flexibility and performance of the overall module.

Dielectric materials are made by blending thermally efficient materials such as alumina and boron nitride with other ingredients, to provide a flexible yet resilient coating on the base plate. An important characteristic of the dielectric layer is the amount of electrical isolation it provides between the copper on the topside and the metallic base plate on the underside. This is known as its dielectric strength. A typical dielectric material may possess a dielectric strength of around 800 V/mil and be coated onto the base plate to a thickness of 8–12 mils (1 mil = one-thousandth inch = 25.4 μm).



Packaged LEDs bonded to a metal PCB using thermal adhesive.

Dielectric materials used on insulated metal circuit boards usually have a thermal conductivity figure in the region of 3 W/mK. This is approximately 10 times the performance achieved by FR4 (flame-retardant woven glass reinforced epoxy resin) PCB material.

A further key requirement of the dielectric layer is to be able to compensate for the different coefficients of thermal expansion of the copper track on the topside of the assembly and the aluminum base plate/heat spreader on the bottom side. →

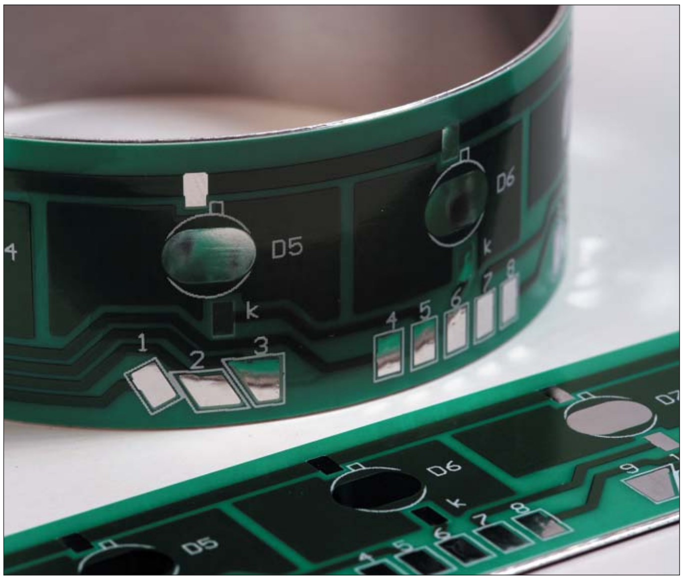


Fig. 1. Universal Science's UniForm technology. Formable metal circuit boards could be used in bollard lighting applications.

Going three-dimensional

Flat sheets of insulated metal circuit board comprising copper foil, a dielectric layer and an aluminum base plate have been available for several years. In the eyes of the forward-thinking LED module designer, the main problem has been that flat sheets of insulated metal circuit board limit them to 2D shapes.

To address this limitation, new dielectric materials are becoming available that have a low modulus, meaning that they are compliant with mechanical stress and strain. These materials not only accommodate the coefficient of expansion of the metal elements of the construction, but also enable parts to be formed into right angles, and even through 360°. This enables designers to realize complex-shaped designs and ones that form a complete circle with either internal or external copper traces (figure 1).

When designing with new, formable insulated metal circuit board materials it is possible to route the tracks around corners, which alleviates the need to use connectors and hard wiring. There are several benefits to this, including enhanced reliability resulting from having fewer junctions and interconnects. Despite the slightly higher cost of the new materials, the overall cost is reduced because fewer components are needed, and assembly time is reduced.

Strength and durability

LEDs themselves are inherently durable. Mounting them on metal-based circuit boards only serves to enhance their robustness and that of the finished module, providing excellent resistance to vibration and mechanical shock.

Automotive lighting clusters provide a good example of how LED modules can provide superior performance compared with traditional filament lamps. On-vehicle applications experience high levels of vibration and wide operating temperature ranges that can cause premature failure of filament lamps. In some operating conditions LEDs can last up to 100,000 hours, which means that they should not require any attention for the life of the vehicle.

The long life of LEDs also simplifies the designers' task because it is less important to make the lighting module accessible for servicing in the finished product. This can result in a neater, more integrated installation and also in potential cost savings.

Temperature modelling

Thermal analysis software packages are available to help prove LED-based module designs before they are committed to manufacture. These software packages gather data from an integrated database about LED performance and specifications along with those of other devices that are mounted on the insulated metal circuit board. This data is combined with other information about elements of the design, including the copper traces, power and ground planes, and vias. The collated information is then processed to produce an accurate representation of the thermal performance of the design.

User-friendly graphical representations of the results enable the design engineer to quickly pinpoint areas that may require attention, right down to component and track level.

Thermal analysis software can bring significant commercial and design benefits by helping speed the time to market and reducing the number of iterations needed to reach a production-ready solution. ●

Links

On our website:
Fact or fiction – LEDs don't produce heat
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About the author

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Car manufacturers make a stand with LED technology

Automotive manufacturers pull out all the stops when it comes to attracting visitors to their stands at the major motor shows, and LED displays and lighting are now commonly used.

Recent motor shows such as those in Frankfurt and Tokyo were packed with LEDs, and not just on the latest concept vehicles. Many companies are using LEDs as part of their exhibition stands, and these range from straightforward high-resolution LED screens to more intricate and creative uses of lighting and low-resolution displays.

Creative displays

CT Creative Technology GmbH, a Germany-based rental company, provided audio-visual media technology for Volkswagen, Saab, Ford and Bugatti at the 2005 Tokyo Motor Show. For the Volkswagen stand (figure 1), CT integrated Barco MiPIX Roadmodules (which combine LED pixel blocks into panels measuring 896 x 896 mm) with a high-resolution (6 mm) Barco ILite 6 XP LED screen measuring 9 m^2. A total of 24 MiPIX Roadmodules were installed over a width of 25 m to form a communication screen. The high-definition video and graphic contents shown on both LED products with different resolution resulted in a highly distinctive effect.

A similar effect was achieved on Saab's stand (figure 2), where three individual LED screens were arranged in an open architecture. Two VersaLIGHT LED screens from Element Labs and a high-resolution

Fig. 1. The Volkswagen stand at this year's Tokyo Motor Show.

Fig. 2. Two VersaLIGHT LED screens and a Barco ILite 6 XP LED display formed an open architecture at the Saab stand in Tokyo.

Fig. 3. LED strips and tiles illuminated the Lexus booth in Frankfurt.

Fig. 5. LED-Balken fittings featured at the BMW Group's Mini stand.

Fig. 4. The installation of LED floor panels at the Lexus booth.

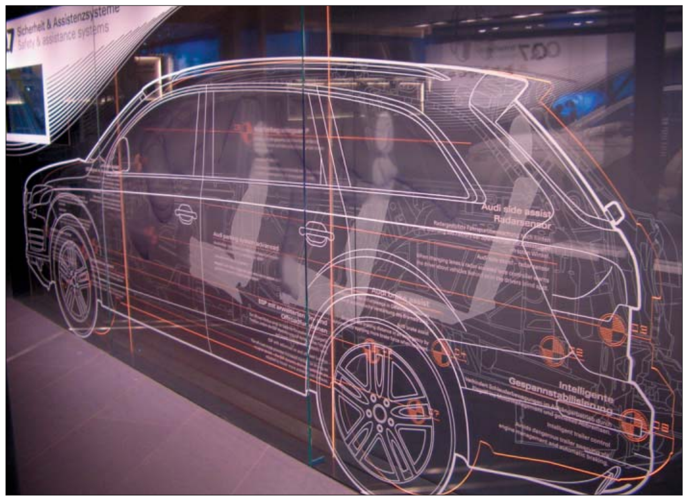

Fig. 6. On the Audi stand, orange LEDs highlighted etched Perspex.

Barco ILite 6 XP LED screen measured 4 × 4 m each. Visitors were impressed by their size and the perfect interaction of the video and graphic contents on the different resolutions of the screens.

Schnick Schnack tiles

Schnick Schnack Systems, a German LED lighting manufacturer, supplied lighting systems for several car manufacturers' booths at the Frankfurt show. Several hundred thousand RGB LEDs were used in an installation on the Lexus booth (figure 3), which consumed about 100 kW of power in white. Around 300 plastic tubes containing in total more than 2 km of LED strips were used to form a 6 m-wide background wall. Each tube could be individually controlled to create a flowing sequence of colors over the entire area of the wall. The illuminated floor was equipped with LED-Kachel B tiles, each containing 16 LEDs and measuring 20 × 20 cm. A total of 7500 LED tiles were built into aluminum housings, providing a 15 cm-deep floor construction (figure 4) that bathed the cars and visitors with a homogenous and warm light.

The BMW Group used 20 LED-Balken 200 and four LED-Balken 120 fittings at the booth of their Mini brand (figure 5). The Balken 200 is a road-proof luminaire for backlighting an area measuring 2.0 × 0.2 m, and consists of 10 independently controllable LED-Kachel tiles. A further 200 LED-Strips 25 were used to light edges and staircases.

The smallest installation was at the Audi booth, made of 64 LED-Strips 12-375 (each 375 mm long, and comprising 30 RGB LEDs with a 12.5 mm pitch) plus the corresponding DMX control system. The strips were placed at the top and bottom of large Perspex walls that contained milled grooves in the shape of a car. As shown in figure 6, the LED lighting was used to highlight certain areas of the car in a special "Audi orange" color.

Lighthouse LED screens

Also at the Frankfurt show, VideoRental supplied Honda with 246 panels of Lighthouse R6 6 mm screen, which were configured as three displays. Two 10.8 × 2.8 m screens dominated the Honda stand, playing a mixture of video and graphics in 1632 × 432 pixel format. "The 6 mm Lighthouse screen ensured that the footage was extremely uniform and attractive, with depth and life-like colours," said a VideoRental representative. "The screen's wide viewing angle ensured that the maximum picture quality was maintained when viewed from any position on the stand or across the hall." The third Lighthouse screen measured 4.5m × 2.90 m and was used by Honda for its press conference.

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Recently published

The following articles can be found on our features page at www.ledsmagazine.com/articles/features:

- LEDs lighting the future. Q&A with Biing-jye Lee, the president of Epistar. In an interview conducted with *DigiTimes.com*, Lee talks about Taiwan's LED industry, the future demand for LEDs, competition from China and Korea, and his company's merger with UEC.

- Microcontrollers provide connectivity of HB-LED lighting products. The combination of HB-LED lighting with a reliable connectivity interface such as DALI or DMX512 will bring additional compelling features to household lighting, writes Dugald Campbell of Freescale Semiconductor.

Coming soon

Among articles to be published shortly on the *LEDs Magazine* website will be:

- The world's largest backlight? Polymer Optics Ltd and Ambisol describe their large-area illumination systems.

- Pulse amplitude modulation – the latest patented technique for driving LEDs.

- Lynk Labs describes its technology for driving LEDs with an AC power supply.

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LEDs and concept cars at the Frankfurt motor show

The annual automotive technology showcase in Frankfurt included many examples of manufacturers experimenting with LED lighting concepts for interior and exterior lighting.

Among the many concept cars unveiled at the 2005 IAA International Motor Show in Frankfurt were several with full LED lighting, including the Ford Iosis and the Renault Egeus (with LED lights supplied by Valeo). Hella in collaboration with LED maker Stanley Electric also unveiled an LED front-lighting concept (see Links). In the Mitsubishi Sportback, designers have arranged the LEDs in a thin, long strip to blend in with the vehicle's sharp lines. LEDs at the outer edge of the headlamp help to illuminate turns.

The Opel Antara GTC concept car is lit entirely with LEDs from Osram Opto Semiconductors. The rear light cluster (figure 1) consists of a "pupil" of seven hexagonal-shaped white Golden Dragon LEDs for the reversing light, surrounded by 12 yellow Golden Dragons, which function as the indicator. A total of 12 red LEDs are used for the brake and tail lights. Nine of these are arranged underneath the "pupil", while the other three emit their light sideways and cause the entire rear light cluster to shimmer. When used as rear lights the LEDs are slightly dimmed, but when used for braking they operate at full brightness to give an effective warning signal.

Toyota unveiled the all-new Toyota RAV4 SUV (figure 2), which features an LED rear lamp that uses nine LEDs for the brake function. Designed with reflector optics, this provides a jewel-like appearance, both in lit and unlit conditions.

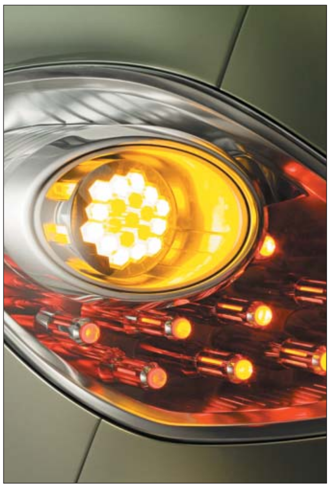

Fig. 1. The Opel Antara GTC concept uses LED lighting from Osram Opto Semiconductors.

Fig. 2. The rear lamp on the new Toyota RAV4 SUV features nine LEDs for the brake function.

Sequential interior lighting

The Lexus GS features a six-step sequential interior lighting system that has a combination of 13 LED spot lamps (figure 3). Upon opening the door, puddle lamps and the door panel are illuminated, followed by the front and rear foot wells. Next, overhead lights illuminate the seats, center console and steering wheel. The ignition button is then lit, indicating where to start the vehicle. When pressed, the button glows orange and starts the accessory features. After the brake pedal is pressed, the ignition button glows green, indicating that the engine will start the next time the button is pressed.

Fig. 3. Overhead LEDs illuminate the center console in the Lexus GS.

Cars of the future

Concept cars demonstrate technology that is expected to reach the market in a few years' time, but some manufacturers are looking even further ahead. Peugeot's Moovie (figure 4), the winner of the third Peugeot Design Competition, features all-LED lighting. This concept car takes advantage of LEDs' compact size and low power consumption, which are big advantages for future mono-transportation concepts.

The Toyota i-unit, whose design is inspired by a leaf, "creates a seamless transformation between the vehicle and human movement, minimizing occupied space and energy consumption with its lightweight and ultra compact size". Its components are made with decomposable and recyclable materials.

Interior illumination

Delphi unveiled some novel LED technologies to enable vehicle manufacturers to provide distinctive interior designs that take illumination into new areas. "Interior illumination has been historically limited

Fig. 4. The Peugeot Moovie (top) and the Toyota i-unit (bottom): could these concepts represent the future of personal transport?

to only a few areas, in places such as dome and reading lamps, lighted visors, and the back lighting of various components," said Dieter Barowski, European engineering director at Delphi's Packard Electric division. "LEDs and our ability to route flexible printed circuits into places where space is a premium opens up a number of new illumination options inside the vehicle."

LEDs have been used to illuminate door sills, as well as for reading lamps, interior courtesy lights, and sun visors. Other applications include LEDs in B- and C-pillar illumination, color change, door handles, and interior roof and other ambient lighting.

Delphi has also developed an ultra-thin application for the central high-mounted stop lamp that is only 6 mm thick, and provides auto makers with greater flexibility for installation owing to its ability to be mounted directly to the window.

The company has also used flexible printed circuits, or Flat Wire, to create low-profile illumination possibilities (figure 5). "These reduce the number of electrical interfaces and assembly complexity, and increase the OEMs' packaging possibilities," said Reinhard Felgenhauer, engineering supervisor at Delphi Packard Electric. "This is a critically important point as one considers the constraints posed by growing vehicle content and the naturally tight routing spaces in which LED illumination is being introduced." ●

LED mirror signal indicators on Toyota Sienna

Gentex Corporation has begun shipping a three-mirror, automatic-dimming rearview mirror system for the 2006 Toyota Sienna, following in the footsteps of the Toyota Avalon. The mirrors darken automatically to reduce glare from the headlamps of vehicles approaching from the rear. The driver- and passenger-side exterior auto-dimming mirrors have integrated through-the-glass turn signals, which consist of an arrow-shaped array of LEDs aimed at the vehicle's blind spots. These serve to warn other drivers of impending turns and lane changes.

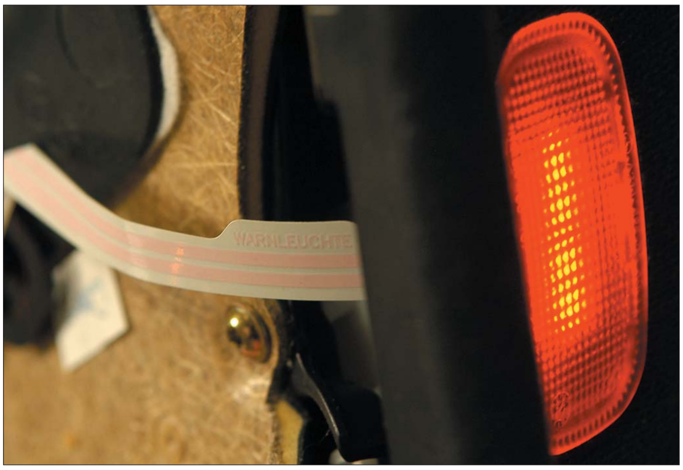

Fig. 5. Delphi's low-profile lighting employs Flat Wire connectors.

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