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

LEDs MAGAZINE

LEDs Magazine Review

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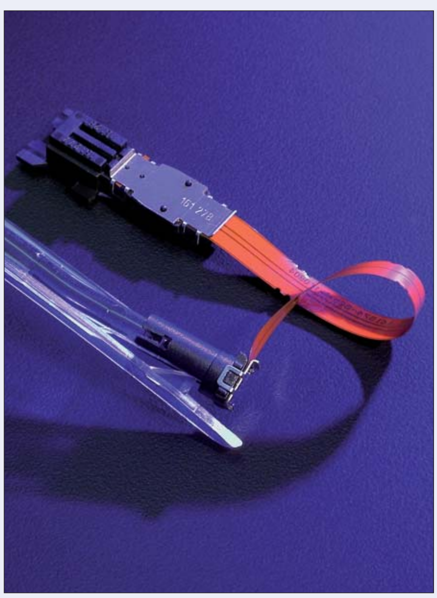
Modern mobile-phone handsets, such as the Nokia N90 shown here, incorporate multiple LEDs. **p9.**



Hella has supplied LED light-guide modules for the new Mercedes-Benz S-class interior. **p23**

Rear-projection TVs using LED light sources sparked huge interest at this year's CES. **p15**

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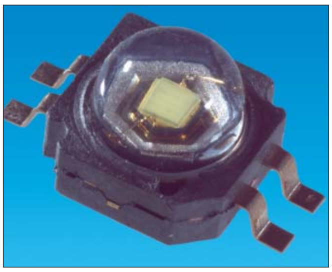
HIGH-POWER LEDS

Lumileds releases Luxeon K2, but XLamp raises the stakes

After a long wait, Lumileds Lighting has released its Luxeon K2 LED, a redesigned, surface-mountable version of the high-power Luxeon package that produces up to 140 lm in white when driven at 1500 mA. Shortly afterwards, Cree unveiled a new and improved XLamp LED, claiming record performance figures of 57 lm and 47 lm/W at 350 mA drive current.

K2 appears at last

The long-awaited Luxeon K2 from Lumileds is now fully released, almost one year after first being previewed. Steve Landau, marketing manager at Lumileds, says there was no specific reason for the long delay. "This is an entirely new product and everything – the chip, the packaging – was redesigned," he said. "It was critical that what we released met the expectations we had established."



Unlike the standard Luxeon package, the K2 can be surface-mounted using standard reflow techniques. The device also has new alignment features and datum reference points that facilitate precision assembly.

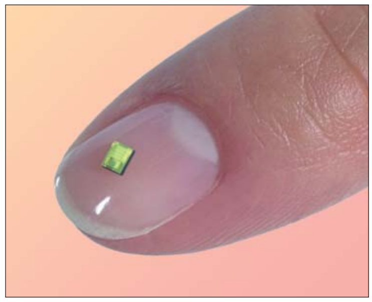
The K2 has a low thermal resistance of 9 °C/W, and tolerates a very high maximum junction temperature of 185 °C for InGaN-based devices (blue, royal blue, cyan, green), or 150 °C for white and AlGaInP-based (red, red-orange, amber) LEDs. Lumileds says that this allows engineers to deliver more light with existing thermal designs by driving LEDs at higher currents. It could also be possible to reduce or even eliminate heat-sink requirements, for example by mounting the LEDs on an FR4 board rather than a metal-core PCB, thereby lowering the cost of system thermal design; and to build applications for use in environments with severe heat conditions.

Lumileds is making the K2 available in two configurations, one tested and binned at 350 mA, the other at 1000 mA. However, there is no fundamental difference between these configurations. All the K2 devices operate over the full range of currents up to the maximum allowable levels of 1500 mA for the InGaN-based devices (including white) and 700 mA for the AlGaInP devices.

White K2 devices binned with a minimum flux of 39.8 lm or a typical flux of 45 lm at 350 mA will have a typical flux of around 100 lm at 1000 mA, or 130 lm at 1500 mA. A second white flux bin is also available, at a higher price point, with a typical flux of 60 lm measured at 350 mA (50 lm/W efficacy), rising to 140 lm at 1500 mA (24 lm/W).

The ability to operate the K2 at any drive current below the maximum provides a huge amount of flexibility, explains David Eastley, product manager for the Luxeon K2 line. "There is not a right or wrong answer as to whether you should operate at 350 mA, 1000 mA or some other current," said Eastley. "This absolutely depends on the application and how you want to optimize the design using the flexibility that K2 provides." There are of course many factors that need to be balanced, including drive current, junction temperature and thermal resistance. "You can determine what your sweet spot of operation is and you can optimize your design," said Eastley, "depending on if you're developing a system for the highest efficacy, or trying to extract the most amount of lumens, or if you want to work without a heat sink."

● More details: www.ledsmagazine.com/articles/news/3/1/30/1

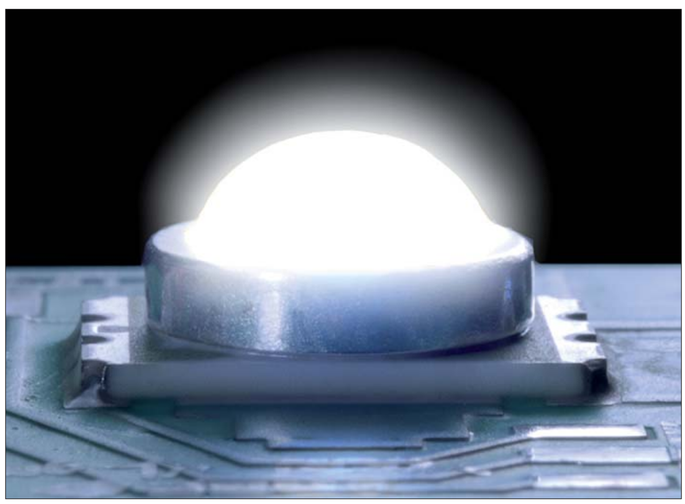


Lumileds has released the Luxeon Portable PWT1, an extremely small high-power LED designed for flashlights and other portable lighting applications. The new emitter generates 26 lm at 350 mA from a package size of only 2.0 x 1.6 x 0.7 mm, and has a lifetime of 2000 h.

White XLamp produces 57 lm at 350 mA

Cree has announced general availability of the latest iteration of its white XLamp 7090 power LED package, which has a typical light output of 57 lm with 47 lm/W efficacy at a drive current of 350 mA. Cree claims that this figure represents "the industry's highest efficacy for white power LEDs at 350 mA".

Mark McClear, marketing director for LED lighting, emphasizes the focus on the 350 mA drive current. "Our analysis shows that the 1 W package driven at 350 mA is the sweet spot for general illumination. You can drive the devices much harder and get more light out of them but the efficiency drops right down. One watt represents the optimization of the overall light output, efficiency, and most economical design." McClear acknowledges that the situation is different for other applications but feels that the case for using 1 W devices in general illumination is hard to argue against.



The high performance of the new XLamp package, designated the XR series, represents higher chip performance, and also an evolution of the package. "We have reduced the thermal resistance from 17 to 8 °C/W [for white and other InGaN-based devices]," said McClear. The value is 15 °C/W for AlGaInP devices, and the LEDs have a maximum junction temperature of 145 °C. The original XLamp will be phased out over the next several months. There is no change to the package footprint or optics with the new device. →

A warm white (2700–4500 K) XLamp has also been introduced to address the emerging market for residential lighting applications. McClear says that the warm white XLamp has typical figures, at 350 mA, of 41 lm and 34 lm/W.

Lumileds promotes pricing structure

At the start of the year, Lumileds made a surprise but welcome move by revealing a new pricing scheme (see www.ledsmagazine.com/articles/news/3/1/32/1) for its Luxeon I and III LEDs, later extended to the K2. Prices for some (but not all) devices are now quoted for orders of less than 10,000 units. Figures are given not only in dollars but also in lumens per dollar (lm/$), clearly encouraging customers to consider this important parameter and compare values between competing LED makers. White K2 devices providing 45 or 100 lm are priced at $3.45, equating to 13 lm/$ or 29 lm/$, respectively. White Luxeon I Lambertian emitters providing 45 lm are priced at $2.99, or 15.1 lm/$.

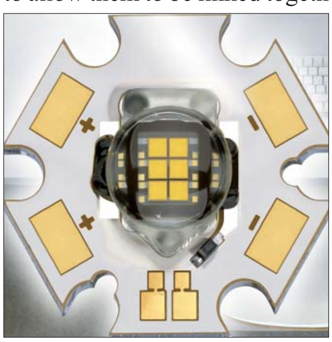
Like other competitors of Lumileds, Cree has not made pricing information available, although Mark McClear says that the XLamp is "priced competitively on a $/lm basis".

- Lumileds: www.lumileds.com
- Cree: www.cree.com/XLamp

HIGH-POWER LEDS

Six-chip Ostar LED produces 420 lm at 700 mA drive current

The newest members of Osram Opto Semiconductors' Ostar high-output LED family – white devices targeting lighting applications – contain either four or six series-connected chips, and have a hexagonal shape to allow them to be linked together into space-saving, high-intensity packages. The devices are designed to be mounted on a heat sink using thermal paste and screws.



The six-chip version produces 420 lm with a specially developed hemispherical lens at 700 mA drive current, or 300 lm without a lens. Power consumption is 15 W. Osram says that the lensed version, which has an efficacy of 28 lm/W, is brighter than a 20 W low-voltage halogen lamp. Four-chip versions produce 280 lm with a lens and 200 lm without, at 700 mA and 10 W.

Osram says that its latest Ostar LED is ideal for a wide variety of general lighting applications, including individual workplace lighting, reading lights, residential and commercial lighting and even specialty flashlights. The devices contain ThinGaN chips that emit light only from the top surface, resulting in high luminance and higher optical system efficiency and reducing the size of optics for lighting applications. The white color is constant from every viewing angle, enabled by placing the phosphor conversion material directly onto the blue chip.

In the last issue of *LEDs Magazine Review* (see www.ledsmagazine.com/articles/news/2/12/26), we described results from Osram's surface-mountable Golden Dragon package; a white device with a lens typically exhibits 89 lm at 700 mA, and R&D results show 126 lm at 1.0 A. However, Osram Opto's CEO, Ruediger Mueller, explained to *LEDs Magazine* that there are limits to increasing the dimensions of SMT devices like the Golden Dragon.

"Because of the thermal mismatch between the different materials, SMT packages are limited in size," he said. "For applications such as lighting, projection and automotive headlights, which require in the order of 500–1000 lm, the multi-chip Ostar package provides a more flexible approach."

- More details: www.ledsmagazine.com/articles/news/3/1/28

LIGHTING FIXTURES

LLF's warm-white LED fixture boasts 54 lm/W efficiency

LED Lighting Fixtures, Inc. (LLF), the company formed last year by several ex-employees of LED maker Cree, has announced performance results from a warm-white-emitting recessed-can fixture. The fixture was tested by an independent lab as providing 700 lm of white light at a color temperature of 2900 K, with a color rendering index (CRI) of 93.

The total power supplied to the fixture from a residential voltage (120 V) AC power source was 13 W, equating to a fixture efficiency of approximately 54 lm/W.

These figures represent an important step in the development of LED lighting, not only because of their magnitude but also because they give a true representation of fixture performance. "Total power consumption should be stated from the AC wall-plug, thereby looking at the overall system performance including all optical (lenses) and electrical (driver) losses," explained LLF's chief technology officer, Gerry Negley. "Also, true performance measurements must be taken at steady-state conditions after achieving thermal equilibrium. Consumers need to know that they can rely on published performance figures."

Negley also says that the LED industry has a great deal to learn about general lighting systems. "We've witnessed a number of significant disparities in the industry between published data and actual performance," he said. Certified measurements verified by an independent third-party – in this case, by CSA International's Atlanta Lighting Laboratory – are also vital.

In January of this year, LLF announced a recessed-can fixture providing 753 lm of white light with an AC power input of only 15.9 W, or 47 lm/W efficiency. Further progress is expected. "We now envision recessed-can fixtures that will use only 6 W to produce the same amount of warm white light as those utilizing 65 W incandescent bulbs," said Tony van de Ven, LLF's managing director. LLF says that it will begin manufacturing the new light fixtures by the end of this year.

Links

On our website:

LED Lighting Fixtures creates 750-lumen recessed light
www.ledsmagazine.com/press/11280

Former Cree employees launch LED lighting venture
www.ledsmagazine.com/articles/news/2/10/28

LIGHTING

Zumtobel establishes Ledon Lighting, invests C$4 m in TIR

Zumtobel Group, a major global lighting company, has set up a new subsidiary, Ledon Lighting GmbH, to focus on LEDs as the lighting technology of the future. The firm has also invested C$4 million in TIR Systems and licensed the Canadian company's Lexel technology.

Ledon Lighting is based in Lustenau in the Vorarlberg region of Austria and is expected to move into its new premises in March of this year. Ledon complements Zumtobel Group's existing LED activities based at Jennersdorf in the Burgenland region of Austria, where TridonicAtco focuses on LED modules and the Lexedis Lighting joint venture concentrates primarily on white LED light engines.

Lighting Services Inc (LSI) introduced the first light fixture based on TIR's Lexel technology at the arc06 show in London in mid-February. The LumeLEX is a track-lighting fixture aimed at retail, museum, and gallery market segments, and is a white-light source that provides similar intensity to conventional sources, with the flexibility to dim and select any color temperature desired.

The new company's efforts will center on the use of innovative LEDs in pioneering lighting concepts and new fields of application. "We expect LED technology to have a far-reaching and dynamic impact on the field of professional lighting," said Zumtobel Group CEO Andreas Ludwig.

"With Ledon Lighting in place, we now cover the entire value chain for LED-based lighting solutions at the Zumtobel Group and have established a solid platform for the lighting of the future," continued Ludwig. "As well as reinforcing our existing brands – Zumtobel Staff, Thorn and TridonicAtco – with new LED products, Ledon Lighting will be using this innovative technology to open up entirely new sales channels and market segments for our group."

Through Ledon Lighting, the Zumtobel Group has also entered into a strategic development and supply agreement with the Canadian company TIR Systems Ltd, and has licensed TIR's Lexel technology. Zumtobel says that Lexel technology will in the future play a significant part in the innovative LED-based products offered by Ledon Lighting.

In addition to the commercial agreement between the two companies, Zumtobel AG has invested C$4 million in TIR Systems Ltd, which is listed on the Toronto Stock Exchange. "For the Zumtobel Group, the strategic partnership with TIR Systems is a perfect enrichment of our dynamically growing LED activities," said Ludwig. "Access to Lexel technology provides us with an important innovative edge."

In the course of 2006, Ledon Lighting says that it will become the first European lighting manufacturer to manufacture products based on Lexel technology. Key fields of application will include professional indoor lighting for the retail, hotel and museum segments.

Links

On our website:

Zumtobel invests $4 million in TIR, licenses Lexel
www.ledsmagazine.com/articles/news/3/1/1

LED joint venture Lexedis launched in Paris
www.ledsmagazine.com/articles/news/2/12/16

TIR teams with Lighting Services Inc
www.ledsmagazine.com/articles/news/2/10/29

ACQUISITIONS

Dialight pays £3 m for solid-state lighting firm Lumidrives

Dialight plc, a UK-based company focusing on applied LED technology, has acquired 100% of the shares of Lumidrives Ltd for £2.45 million in cash and £550,000 in Dialight shares (approximately $5.3 million in total). Also based in the UK, Lumidrives is one of the leading suppliers of solid-state lighting fixtures and components to the European architectural-lighting market.

From its facility in Knaresborough, UK, Lumidrives will be responsible for Dialight's growth in the European solid-state lighting market. Over the last four years, Lumidrives has grown considerably, with annual revenues and gross assets now exceeding £3 million and £1 million respectively.

Lumidrives recently supplied color-changing LED fixtures and LED drivers for the Five Boats building complex in the inner harbor of Duisburg, Germany. The complex of six-floor buildings was designed by British architect Nicholas Grimshaw, while German-based lighting specialist Spectral developed the unique lighting concept and carried out the installation.

Dialight's chief executive Roy Burton explained to *LEDs Magazine* the reasons for acquiring Lumidrives. "They have a nice product portfolio, they have a good customer base and they have a great management team in Gordon Routledge and Alison Ambler," he said. "They have done an outstanding job in the last four years to make Lumidrives a significant force in solid-state lighting in Europe."

Burton says that Dialight will allow the successful Lumidrives operation to continue as before, without trying to absorb and integrate the company. "Lumidrives will continue pretty much unchanged," said Burton. "They will have access to all of Dialight's capabilities and will be able to leverage whatever they need to penetrate the European solid-state lighting market."

Dialight has many strengths that Lumidrives can benefit from, says Burton: "We buy significant amounts of high-power LEDs; we have very significant engineering resource in the US, Germany and Newmarket [UK]; we have test capabilities; we have an IP portfolio that they can draw on; we have low-cost manufacturing in Mexico if they decide that's what they want to do; and we have relationships in countries and with customers that may be of use to Lumidrives."

The future direction of Lumidrives will be decided by its management team, says Burton, but they will continue in the architectural lighting business and in the lighting-components business – which includes drivers, optics, and light engines – as well as moving into the industrial-lighting arena. "The intent at the moment is to keep the Lumidrives brand and move forward with Dialight Lumidrives as the company name," added Burton.

In September 2005, Dialight changed its name from Roxboro Group plc to reflect the company's new focus on LED technology and solid-state lighting. Almost all of Dialight's revenue now comes from LED-related activities. "All of our investment and all of our growth is now in the LED business," said Burton.

Links

On our website:

Roxboro becomes Dialight, focuses on LED-based products
www.ledsmagazine.com/articles/news/2/9/2

Dialight acquires Lumidrives for £3 million
www.ledsmagazine.com/articles/news/3/1/13/1

BUSINESS & MARKETS

HB-LED market experiences massive slowdown in growth

Despite stronger sales of mobile phones in 2005 than expected, the market for high-brightness LEDs grew just 8%, according to Michael Hatcher, editor of *Compound Semiconductor* magazine. At the Strategies in Light 2006 conference in San Francisco, California, industry analyst Bob Steele said that the market for packaged HB-LEDs was worth $4 billion in 2005.

That represents a massive slowdown in annual growth from the average of nearly 50% seen over the past few years, and is largely the result of a stagnating mobile appliance market. Excess capacity slashed keypad backlight selling prices in half, reported Steele.

Increased penetration of LED-based camera flashes used in phones and a 24% increase in the volume of chips shipped maintained the value of the market for HB-LEDs in mobile applications at just over $2 billion, similar to the 2004 figure. But that figure will remain flat as the mobile sector becomes increasingly commoditized, with market growth now reliant on other applications, in particular LED-backlit notebook computers and televisions.

Steele predicted that the overall LED market would grow by 10% in 2006, reaching $4.4 billion, and that LCD backlights and automotive headlamp applications will contribute meaningful revenues in the 2007–2008 timeframe.

Space Cannon selects Cree LEDs for lighting

Space Cannon VH SpA, an Italian lighting designer and manufacturer which provided lighting for the Olympic Winter Games in Turin,

The Olympia Museum in Athens, Greece, is lit using Athena LED bars manufactured by Italian company Space Cannon.

has signed an agreement to purchase approximately $5.4 million of XLamp power LEDs from Cree.

- More details: www.ledsmagazine.com/articles/news/3/1/9/1

Nichia reports results

Nichia Corp, the world's leading LED manufacturer, is expected to report sales of ¥195 billion ($1.645 billion) for the fiscal year ended December 31, 2005. This figure will represent a decrease of 5.5% from the figure of ¥206 billion reported for fiscal 2004. This will mark the first time since fiscal 1993, when Nichia launched its blue LED products, that both profit and revenue have fallen.

- More details: www.ledsmagazine.com/articles/news/3/2/5/1

Everlight buys Fairchild LED product lines

Everlight International Corp, the US subsidiary of Taiwan-based LED manufacturer Everlight Electronics Company Ltd, has purchased the LED and LED display product lines of Fairchild Semiconductor, the US-based electronics company. For several years Everlight has been the foundry manufacturer of LED and LED display products sold by Fairchild.

- More details: www.ledsmagazine.com/articles/news/3/1/3/1

Arrow Electronics introduces specialist LED group

The North American Components business of Arrow Electronics has formed a group solely dedicated to supporting manufacturers of products containing high-brightness LEDs. Arrow recently added Harvatek International, a leading manufacturer of surface-mount LEDs, to its supplier listing.

- More details: www.ledsmagazine.com/articles/news/3/2/6/1

Cyberlux enters OEM partnership, receives patent

Cyberlux has entered a strategic OEM partnership with a leading and as yet unnamed retail product company that can provide distribution in over 20,000 retail customer locations. The company also has been awarded a patent for emergency-lighting systems.

- More details: www.ledsmagazine.com/articles/news/3/2/1/1

Permlight joins California Lighting Technology Center

Permlight Products has become an affiliate member of the California Lighting Technology Center (CLTC) at University of California at Davis. Permlight has also sponsored a UC Davis design class that involves students in the design of "next-generation lighting" for home and commercial applications using advanced LED systems.

- More details: www.ledsmagazine.com/articles/news/3/1/14/1

VEHICLES

White LEDs used for daytime running lights on new Audi S6

Audi's new S6 model features white LED daytime running lights (DRLs) incorporated into the front bumper. The five LEDs on each side create a highly distinctive appearance. Other Audi cars have DRLs using four or five white LEDs located within the main headlamp.

Other articles on the VEHICLES channel of our website include:

- The Renault Altica concept car uses novel LED lighting technology: micro-optical features in the headlamp cover create a veil of light in certain operating modes while leaving the main and low beam functions unaffected.
- Lighting designer Visiopia has used PerkinElmer LEDs for Mazda's Kabura concept car.
- The US Army has tested white LED headlights on a Hummer vehicle in a frigid environment.
- Ford showcases LED-based adaptive front lighting on a concept car, while Boeing will use LED lighting in its 747-8 jumbo.

PATENTS

Osram and Avago sign LED patent cross-license deal

Osram Opto Semiconductors GmbH and Avago Technologies have signed a limited patent cross-license agreement, with each side gaining the rights to use the other's LED technology. Osram has granted Avago a license for several patents to manufacture and sell white LEDs with a specific conversion technology, as well as surface mount (SMT) LEDs. In return, Avago has granted Osram a license covering LED systems for projection and flat-panel LCDs.

Other articles featured on our PATENTS & LICENSING channel (www.ledsmagazine.com/articles/features/1/4/8) include:

- Osram Opto Semiconductors claims to have won its patent action in the US against Dominant Semiconductor. However, Dominant has also claimed a partial victory.
- Nichia has filed patent-infringement claims against its rival LED maker Seoul Semiconductor, and also against Creative Technology, which uses Seoul Semiconductor's LEDs to backlight the LCD screens in its MP3 players. The complaint alleges infringement of four US design patents assigned to Nichia.
- Nichia has contacted Harvatek to advise of alleged infringement of a design patent. Meanwhile, the Japanese LED maker is planning to give up its rights to a contentious wafer-manufacturing patent.

ARCHITECTURAL

LightLed brightens Barcelona tower with 4500 L3 RGB lights

Color-changing LED lights from LightLed, a subsidiary of the Spain-based Odeco Group, are illuminating a high-profile office building in the Spanish city of Barcelona. The Agbar tower, the latest work of French architect Jean Nouvel, houses the Barcelona Water Company and rises 142 m above the city centre. A total of 4500 L3 RGB lights, each containing 18 one-watt RGB Luxeon LEDs, illuminate the tower's 32 floors and are controlled from a single computer.

- More details: www.ledsmagazine.com/articles/news/3/2/2
- ARCHITECTURAL LIGHTING channel: www.ledsmagazine.com/articles/features/1/5/2

DISPLAYS

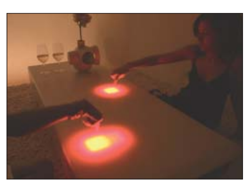
LED screens provide backdrop for UK's popular-music awards

LED screens provided the backdrop for this year's Brit Awards, the annual UK music industry event. XL Video provided three high-resolution Barco iLite 6 XP LED screens, each measuring 5 m wide by 7 m high. The sections could be brought together to form a single screen with a resolution of 2048 × 1024 pixels, or positioned separately as shown here for Paul Weller's performance. The screens were hung from a 55 m-long rail and moved by an automated system supplied by Kinesys.

- More details: www.ledsmagazine.com/articles/news/3/2/27
- SIGNS & DISPLAYS channel: www.ledsmagazine.com/articles/features/1/5/6

DECORATIVE

Sensacell unveils interactive, touch-screen lighting system



Sensacell Corp has unveiled the Modular Sensor Surface – an architectural-scale touch-screen that combines LEDs with capacitive sensors. The modules measure 6 × 6 inches and contain 49 LEDs as well as proximity sensors to detect movement up to 6 inches away through any non-conductive material.

- More details: www.ledsmagazine.com/.articles/news/3/2/28
- ENTERTAINMENT & DECORATIVE LIGHTING channel: www.ledsmagazine.com/articles/features/1/5/3

LEDs in mobile handsets face new competition and shift in emphasis

Mobile-phone handsets still represent the largest segment of the high-brightness LED market, and camera flash is an exciting emerging application. However, as **Tim Whitaker** reports, competition is stepping up from electroluminescent, xenon and OLED technologies.

The mobile-phone handset market has been the driving force behind the incredible growth in demand for high-brightness LEDs in the past seven to eight years. However, this growth has already started to decelerate, due to slower growth in handset sales coupled with rapid declines in the price of certain types of LED devices. However, other applications such as camera flash are just emerging and will have a strong positive effect.

A market study recently released by Strategy Analytics estimated that revenues in 2009 from the LCD and keypad backlighting segments of the LED handset market will be 41% lower than their peak in 2004. However, this decline will be offset by the emerging market for LED flash, expected to grow at a compound average annual growth rate of 87% during the same period (for further information, see Handset LEDs: camera phones offer bright spot in tumultuous cellular handset market). By 2009, says Strategy Analytics, LED flash will represent 36% of the total handset LED market of $1.3 billion (see figure 1 on p10).

Despite still being the largest HB-LED application, the mobile handset LED market is now attracting much less attention than emerging markets such as architectural lighting, LCD backlighting, automotive front-lighting and general illumination. However, many leading LED manufacturers are still heavily involved with handset LEDs.

"We see the mobile market as being quite healthy and continuing to grow," says Dan Doxsee, sales manager at Nichia America. "There is a generally negative air at industry conferences, with more emphasis placed on attention-grabbing architectural applications, for example. However, such applications tend to be project-based and have not so far driven significant LED market growth."

Avi Elmaleh, application engineering manager at Rohm Electronics in San Diego, California, agrees that the market for LEDs in handsets and other portable appliances remains strong. "There are good opportunities in keyboard backlights, LCD backlights, camera flash and handheld devices such as MP3 players," he says. "Rohm continues to introduce new high-brightness LEDs for this market."

Patrick Dearden, sales executive at Stanley Electric UK, says that his company is continuing to develop new technologies and techniques to offer a total solution for mobile-phone illumination. "This involves new ways of utilizing LED light output for more efficient, brighter and more interesting light patterns," says Dearden. "We believe that during the coming years, techniques involving more than simply standard LED technology for this market will be the driving force in developments."

The Nokia N90 has a 2.1 inch main LCD screen that can rotate through 90°, a second display on the outer cover and a 2 Mpixel camera with integrated LED flash (upper right).

LEDs in handsets

A typical new handset contains between eight and twelve HB-LEDs for a variety of functions, some of which are illustrated in figure 2 on p10. The key areas of demand for LEDs in handsets are:

- **LCD screens:** LEDs are used in the backlights of LCD screens, providing single colors for monochrome displays and white light for color displays. At present the only significant competing technology is organic LED (OLED) technology, which is an alternative to LCD technology and does not require a backlight.
- **Keypads:** most handset keypads are illuminated using LEDs, although a small number of handsets use electroluminescent (EL) technology.
- **Camera flash:** low-resolution phones have a basic "fun" flash which provides a small amount of additional lighting, but higher-resolution phones now have better flash units which can be implemented

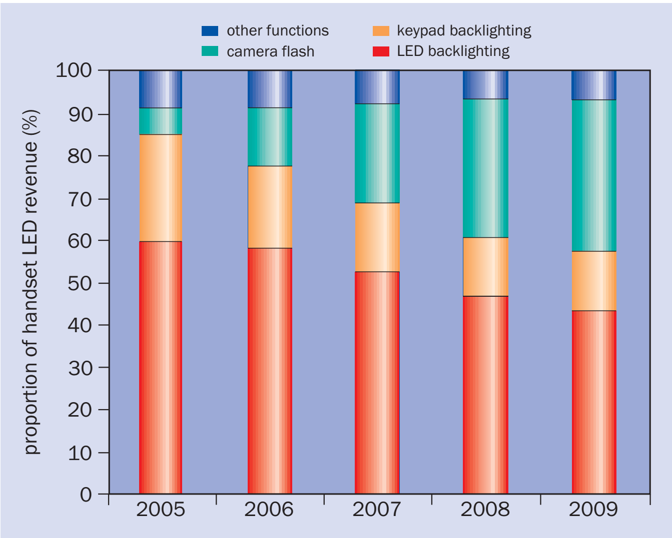


Fig. 1. Revenue from the LCD and keypad backlighting segments is set to decline, while camera flash will become a key application for LEDs in handsets. (Courtesy of Strategy Analytics.)

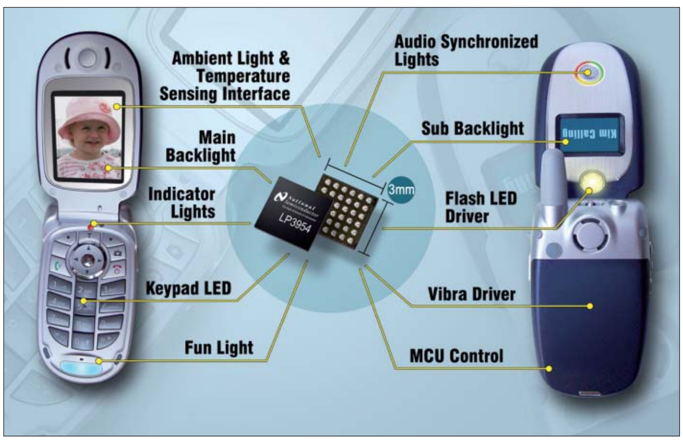


Fig. 2. Applications for a driver IC illustrate a number of functions fulfilled by LEDs in a typical clamshell-style handset. (The ambient light sensing, vibra driver and MCU control functions do not relate to LEDs.) (Courtesy of National Semiconductor.)

using either high-power LEDs or xenon technology.

- **Other features:** many other handset functions use LEDs including ringer lights as well as the examples in figure 2 – audio-synchronized lights (which flash in time to music), indicator lights and fun lights.

A number of trends drive the consumption of LEDs in handsets and these are shown (in no particular order) in table 1, p11. Over the past several years, the rapid growth in 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 by 2004, according to Strategy Analytics.

However, although total unit shipments will continue to grow, overall handset LED revenues have started to decline. While annual handset shipments will continue to grow through 2010, when more than 1.2 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 (ASP) experienced in these two segments, both markets will decline from 2004 to 2010.

LCD backlighting

The backlights in LCD screens used in mobile phones typically use side-emitting LED packages, and the trend is towards higher-brightness devices and reduced thickness (height) packages, enabling thinner handset form factors. "Most designs use 0.8 mm-thick packages, and new designs with 0.6 mm devices are going forward," says Wolfgang Lex, director of marketing for LEDs at Osram Opto Semiconductors. "Upcoming requests for 0.4 mm are on the horizon. This is a challenge for LED makers, as flatter side-emitting packages have less-efficient light extraction." However, says Lex, until the package size approaches the dimensions of the chip there is still room for packaging innovation.

Citizen Electronics recently developed what it described as "the world's thinnest backlight unit" with an overall thickness of 0.65 mm. The product is 23% thinner than the company's existing models, and is produced by combining an optical sheet with a white LED to create the backlighting source and light-guide. The thickness of both the LED lamp and the light-guide is only 0.4 mm.

Nichia, the leading supplier of white LEDs for handset LCD backlighting, continues to focus on thinner and higher-brightness devices. "The main volume is at thicknesses of 0.8 and 0.6 mm, with brightness values around 1.5 cd," says Nichia's Dan Doxsee. "There is significant volume at 0.6 mm, and 0.5 mm devices are also available now. The next generation of products that Nichia will introduce during 2006 will have brightness values around 1.8 cd and an efficacy of 80 lm/W."

LEDs are also required for displays in newer mobile applications. "LEDs used for LCD backlighting in mobile phones are also being widely adopted for personal entertainment devices such as MP3 players," says Nichia's Dan Doxsee. "This has driven further growth rapidly."

A significant percentage of MP3 players use OLED (organic LED) displays, which represent the main competition for LED-backlit LCDs in mobile applications. OLED displays are an alternative, self-emissive technology that doesn't require a backlight. OLED screens are already in use in the secondary screens in flip-phones (clamshell handsets), with about 21 million units shipped in 2005, according to Strategy Analytics. MP3 players are likely to overtake handset sub-displays as the major consumer of OLEDs in 2006. However, OLED technology has yet to penetrate the main screen in handsets, with the exception of some trial models.

Another technology driver that will affect LED consumption is the development of new LCD schemes such as field sequential color (FSC). Full-color LCDs are expensive, and FSC uses a monochrome LCD with an RGB backlight, presenting sequential red, green and blue images at a rate that makes the eye see a single full-color image. "The LCD maker is able to eliminate all the expensive color filters," says Osram Opto's Lex. "System costs can decrease, although the LED cost might be higher initially."

Keypad backlighting

In addition to thinner form factors, which have caused some manufacturers to turn to EL technology (see below), uniformity is emerging as a key factor in keypad design. In a "classical" configuration,

Table 1. Trends driving LED consumption in handsets

Market driver	*Details*
more handset shipments	Since every handset contains several LEDs, the overall growth in the handset market (from 823 million units in 2005 to 1222 million in 2010) is positive for unit shipments of LEDs.
price pressure	For some handset applications, notably keypad backlighting, LEDs have become commodity products and competition has forced prices very low.
new functions	As handsets become more complex there is an increasing demand for LEDs used in functions such as camera flashes, ringer lights and other indicators.
color screens	Although 73% of handsets shipped in 2005 had color screens, this proportion will increase to 95% by 2010, continuing the demand for white LEDs used as LCD backlights.
larger, brighter screens	Vivid displays are a key differentiator for side by side comparison of handsets. In turn this requires brighter (or in some cases more) LEDs for the LCD backlight.
secondary screens	The trend towards clamshell phones, which usually have a secondary screen, has created more demand for LED backlights. However, these displays are small, low brightness and often monochrome, and some use OLED technology.
brighter, more uniform keypads	While brighter keypads require brighter (or more) LEDs, the trend to combine LEDs with light-guides to provide uniform backlighting will reduce the demand for LEDs.
camera phones	Camera phone shipments will increase from 391.7 million units in 2005 to 790.9 million units in 2010, of which 644 million units will incorporate LED flash modules. The vast majority of these will be high-power LEDs enabling good flash performance in conjunction with cameras with a sensor size of 2 Mpixels and above.
competing technologies	There are several technologies that could reduce the consumption of LEDs in handsets; electroluminescent (EL) technology in the keypad, xenon in the flash function and organic LED (OLED) technology, which is an alternative display technology to LCD that does not require LED backlighting.

Examples of the key trends that are driving LED consumption in a positive or negative direction. (Courtesy of Strategy Analytics.)

several top-emitting LEDs are used to illuminate the backlight. “More intelligent designs will use brighter LEDs in a decentralized position with the light guided throughout the keypad,” says Lex.

Most if not all handsets available today do not have nice backlighting systems, says Patrick Trueson, European product marketing manager at Avago Technologies. “You will always see spots around the keypad. In the past, no-one really worried about this as long as you could see the keypad in low light. However, handset makers are now investing in high-performance light-guide systems. This will mean fewer LEDs, but the light will be better distributed around the keypad area.” As this trend progresses, side-emitting LEDs are likely to be required for keypads.

Another trend will be color on demand, says Lex, allowing phone operators to select a branded corporate color (e.g. pink for T-Mobile). “Just as we make white by combining a blue chip with a phosphor, if we choose a different phosphor we can get other colors such as pink or lemon,” he says. Citizen also supplies its Pastelite range of LEDs in 12 different pastel colors.

The next step could be to use RGB LEDs and let consumers choose their own colors. “Blue and white are the most common colors today, with AlGaInP colors used in some handsets, but RGB could allow the user to decide which color they would like to have,” says Trueson. “Today, the price of RGB devices is higher than blue or white [ones], but prices are falling to a level where handset makers will start to consider them.”

EL technology for keypads

The main competition for LED keypad backlighting is EL technology. Some dismiss it as an old approach with little to offer handset designers. However, the impact of handsets such as the Motorola RAZR V3 handset (figure 3, p12), which uses EL backlighting, is difficult to ignore.

Most of the major handset makers as well as many of the smaller OEMs are believed to have used and evaluated EL technology in at least one of their phone models. It’s estimated that there are at least 65 models on the market that use EL technology in the keypads.

EL technology creates light by subjecting a phosphor material to a high-frequency AC supply. EL was used in the early days of monochrome displays, but is not bright enough for color displays, which are backlit with HB-LEDs.

The key advantages of EL technology are uniformity and a very thin form factor. The RAZR V3 is a clamshell phone only 13.9 mm thick when folded, and EL technology plays a key role by enabling its thin keypad. The touchpad is covered in a nickel-plated copper alloy with numbers and symbols etched through to the light-emitting EL layer.

The RAZR V3 uses Rogers DUREL DFLX substrate-free EL lamp technology. Mark Seelhammer, business opportunity analyst at Rogers, describes DFLX EL lamp technology as a “zero-thickness proposition” in which the light-emitting sheet replaces an existing layer of material within the standard keypad structure.

The keypad is constructed by placing metal domes onto a circuit board. First, the domes are placed on a carrier sheet of polyester (replaced by EL material in the RAZR case) and this metal dome sheet is adhered to the circuit board. The polyester or EL material sits between the metal domes and the keypad actuators. Since DFLX EL lamps are substrate-free, this provides flexibility and enables the sheet to conform to the movement of the keys (i.e. the domes and actuators).

“Previously, a through-hole would have been required between the actuator and the metal dome,” says Seelhammer. In other words, the EL sheet had to be removed from beneath the keypad at the point where light emission was actually required.

Common EL colors are amber, green, green-blue and blue. Other colors are created using filters or by using EL materials in combination with down-converting pigments. Because EL is a screen-printed

Fig. 3. The Motorola RAZR V3 uses EL technology for keypad backlighting, and is only 13.9 mm thick when folded.

Fig. 4. Sony Ericsson's K750i handset has a 2 Mpixel camera and two high-power LEDs to provide additional illumination for low-light conditions. However, the company also sells an add-on xenon flash unit for "proper" photography.

technology, different sections of a sheet can be coated with a different combination of materials to create different colors. For example, a single EL sheet can easily create the distinctive green and red colors used for the "Send" and "End" keys.

EL lamps are powered using drivers that convert DC input to AC output. Although some designers may be concerned about integration and electromagnetic interference (EMI), which they perceive to be associated with high-voltage AC technology, Seelhammer states these issues are manageable, given the technology's 10 year history in handsets and recent examples such as RAZR. "Designers are often not familiar with EL and, in particular, with Rogers' EL lamps and custom drivers, which work together to reduce EMI concerns," he says.

HB-LEDs are brighter than EL technology, but EL wins in terms of uniformity. "HB-LEDs produce light hotspots even when currently available light-guiding is used," adds Seelhammer. "EL lamps produce uniform emission."

Investments by OEMs in light-guiding technology have already begun to improve the backlighting uniformity that can be achieved with LEDs. Even so, EL technology is likely to remain the major competitor for LEDs in keypad backlighting for the foreseeable future.

Camera flash: LEDs versus xenon

In a recent *LEDs Magazine* Review article ("Handset LEDs: camera phones offer bright spot in tumultuous cellular handset market"), Asif Anwar of Strategy Analytics described the growth in demand for high-power LEDs in camera flash, driven by the introduction of cameras with higher pixel counts and consumers' growing awareness of their handsets' image-capturing potential.

LEDs are widely used in camera phones, often in the form of three to five low-power LED chips plus phosphor in a single package. Such devices do not provide good flash performance, especially at distances above about 1 m. Xenon flash technology, used almost universally for film cameras and stand-alone digital still cameras (DSCs), is currently capable of outperforming the best LED flash by a factor of four to five in terms of illuminance, allowing better image capture when the objects are further from the camera. A xenon flash is a cylindrical glass envelope filled with xenon gas. A several-kilovolt potential is applied in order to exceed the breakdown potential of the gas, at which point a high current surge produces intense light.

A DSC has more space to accommodate a xenon flash, and the battery capacity is devoted to the camera and flash functions, which is obviously not the case in handsets.

LEDs offer distinct advantages in terms of size, both of the light source and its associated drive circuitry, and power consumption.

Flash module makers such as PerkinElmer are taking steps towards miniaturization. The limiting factor is the capacitor which is used to store charge to fire the flash during the "explosion", i.e. the light-producing event.

Brian Hermes, major account sales manager at PerkinElmer, says the company expects to reduce the size of its xenon modules by about 10% every six months. "We have visibility for how this can be achieved through the next three years," he says. "If we keep reducing our size we'll be where we need to be, except perhaps for ultra-thin phones."

Current handset models with xenon flash – there are about six models now available in the Korean market – have bulkier designs and include the Kyocera A5502K, which contains a flash module supplied by Stanley Electric Co., Ltd. This features both continuous LED lighting suited to streaming video and a miniaturized xenon flashlamp supplied by PerkinElmer. Certain handsets from Nokia and Sony Ericsson (see figure 4) contain integrated LEDs for low-light conditions, while add-on xenon modules enable high-quality photography.

LED maker Stanley has a long history of supplying xenon flash modules, which incorporate drivers and auto-focus components, to camera and DSC manufacturers. The company has also integrated its own LEDs into flash modules for mobile phones, and is developing both xenon and LED solutions. "Stanley is striving to reduce the size of xenon flash units, and also to improve the light output and color-rendering capabilities of the LED flash modules," says Stanley Electric UK's Patrick Dearden. →

Table 2. Xenon and LED technology compared

	Xenon	*LED*
light output	high	low to medium
duration	single pulse for flash	single pulse for flash, continuous for video or flashlight
charge time	3–5 s	nil
power consumption	8 kV trigger, 300 V at 100 A	200–800 mA at 4.5 V
total size	large, limited by capacitor	about 40% smaller than xenon
EMI	yes, thanks to the transformer	no
color quality	broadband emission close to sunlight	tends to be cold bluish-white
cost	comparable	comparable

LEDs and xenon will compete in handsets with high-resolution camera sensors. (Courtesy of Strategy Analytics.)

Although xenon modules provide better illumination than LEDs, they take several seconds to recharge, and can't be used for continuous illumination as a light source for shooting video or as a flashlight.

However, xenon modules have a very sharp cut-off acting like a shutter to improve the quality of photos, particular where the subject is moving, says Hermes. "Xenon also produces a broadband emission spectrum with a color temperature of around 6500 K, which is closer to sunlight and more suitable for photography than the cooler bluish-white emission usually found with LEDs," he adds. However, LED makers are taking steps to address this issue.

The further penetration of xenon flashes into handsets will be influenced by several factors in addition to miniaturization, says Hermes. "One is the need for xenon flash to be designed into a global phone model rather than a regional [i.e. Korean] model. A second factor is the trend towards higher-pixel-count cameras and the desire among consumers to use camera phones for 'serious' photography."

The performance advantages of xenon become significant for sensors with more than 2 Mpixels. For lower-resolution arrays, the pixels are relatively large and can accept light easily, so the performance difference between xenon and LED is relatively insignificant. "Most of the CMOS camera sensor manufacturers we talk to say the crossover point is 2 Mpixels," says Hermes. "Above this point is the target zone for xenon." ●

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CES exhibits herald the arrival of televisions based on LEDs

LEDs provide a number of advantages for microdisplay-based rear-projection TVs, and many consumer products will be launched in 2006, says **Chris Chinnock** of Insight Media.

While many in the high-brightness LED field are focused on specialty lighting and, eventually, general illumination applications, there has been a small but dedicated effort to use LEDs in projection systems – in particular, rear-projection TV (RPTV). Now this effort is coming to fruition. At January's Consumer Electronics Show (CES) in Las Vegas, Nevada, there were five public demonstrations of RPTVs using LED light sources from Samsung, Akai, Hewlett-Packard (HP), JVC and Sanyo (see figure 1), with several models planned for introduction in 2006. For more on other products shown at CES 2006, see Insight Media's "Best Buzz" awards.

If you think rear-projection TVs are the big, dim and fuzzy sets based on cathode-ray tube (CRT) technology, think again. In the last couple of years, new RPTVs using microdisplays – tiny electronic displays less than an inch in diagonal – have swept through the industry, capturing big market share and rapidly sending CRT-based RPTVs into oblivion.

These microdisplay RPTVs (MDTVs) offer high-definition resolution and much better contrast and brightness, as well as thinner, lighter cabinets. Additionally they are less expensive than plasma or LCD TVs.

The three principal microdisplay technologies are 3LCD, digital light processing (DLP) technology, and liquid crystal on silicon (LCOS) (see box, p16). MDTVs based on all three technologies with LEDs as the light source were demonstrated at CES.

Fig. 1. At the 2006 Consumer Electronics Show, Akai demonstrated 46 and 52 inch rear-projection TVs based on DLP technology with an LED light source (top). Sanyo had a prototype LED-based 3LCD television, shown on the left next to a 50 inch plasma display (bottom). (Courtesy of Insight Media.)

Drawbacks of arc lamps

Current-generation MDTVs use an ultra-high-pressure mercury arc lamp to illuminate the microdisplay imagers. While these lamps are very efficient and produce a lot of light output, they run very hot and have a limited lifetime, typically about 6000 h. Depending on how often you watch your TV, you could have to replace the lamp in two to five years – at a not inconsequential cost of $250–400. This is not attractive to set makers or consumers.

There are other trade-offs with MDTV optical design. While the arc lamps are efficient, the optical systems that must collect the light (polarizing it in some cases) and image it onto the microdisplay, then pass it through a projection lens to the screen, are not very efficient. So a 120 W lamp typically requires a high-gain screen to have enough brightness when viewed head-on. But high-gain screens mean that the brightness falls off with angle in the horizontal direction, and even more sharply in the vertical direction. This is a disadvantage compared with plasma and LCD TVs, which have wide viewing angles (and long product lifetimes).

MDTV developers can use screens with low gain (a wide viewing angle), but that typically requires a higher wattage lamp. The penalty for this choice is much shorter lifetime.

Another issue is the color spectrum of the arc lamps. The spectral profile has a big spike in the yellow and weak output in the red. That means optics must remove the yellow and tone down green and blue to create a white point that is balanced. This, in large part, accounts for the inefficiency of the light engine.

New technology has now been developed to utilize this bright yellow segment by adding it to the red, green and blue gamut to create a four-color primary system. This creates a more colorful image and

Microdisplay projector technology

By Tim Whitaker

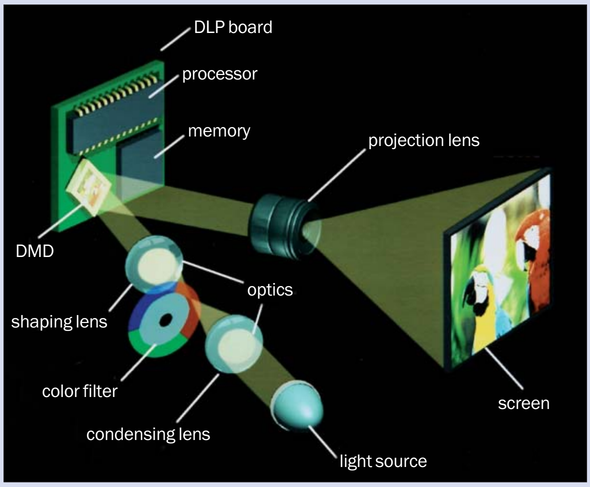
The three principal microdisplay technologies are 3LCD, digital light processing (DLP) technology, and liquid crystal on silicon (LCOS).

DLP technology

Invented by Texas Instruments, digital light processing (DLP) technology is essentially a state-of-the-art optical switch based around a digital micro-mirror device (DMD) also known as the DLP chip. This is a rectangular array of up to 2 million microscopic mirrors that can tilt back and forth in response to digital on and off signals. The mirrors, one for each pixel, reflect light onto the rear of the TV screen. A white pixel is produced when the mirror is tilted towards the light source, and a black pixel if the mirror is tilted away. The DMD mirrors can switch thousands of times per second.

To introduce color, DLP systems using arc lamps have a color wheel between the light source and the DMD mirror panel. As the color wheel spins, it allows red, green, and blue light to fall onto the mirrors sequentially. In older or lower-spec projectors the color wheel is blamed for the “rainbow effect”. Some systems use three DMD chips, one for each color.

For more information, see www.dlp.com.



Schematic of a DLP-based rear-projection TV. (Courtesy of Texas Instruments; see also www.dlp.com.)

3LCD projection technology

3LCD is the most widely used projection technology, and uses three high-temperature polysilicon (HTPS) LCD panels. White light, usually from a high-pressure mercury arc lamp, is split into red, green and blue, and each color passes through a dedicated LCD which modulates the light and produces an image. The images are recombined and projected onto the screen. Unlike DLP, there is no color wheel. Single-color LEDs can be used as the light source, one per LCD. Mini-projectors with LED light sources use this technology, as did Sanyo’s demo at CES.

For more information, see www.3lcd.com.

Liquid crystal on silicon (LCOS)

While 3LCD is a transmissive technology (light passes through the LCDs), LCOS is reflective. The LCOS chip either reflects or blocks light for each pixel according to the state of the liquid crystal, therefore acting in a similar way to the mirror (DMD) in the DLP technology system. LCOS projectors use either three chips, one for each color, or a one-chip system in combination with a rotational prism mechanism or even color wheels. JVC demonstrated an LCOS-based RPTV with an LED light source at CES.

improves efficiency and light output.

So MDTV developers are working in a tight design space. The arrival of LEDs is hugely exciting and will have a big impact on the market. Here’s why.

LED light engines

The benefits of LED illumination are substantial and real. By replacing the arc lamp, the lifetime of the light source can be extended from perhaps 6000 to at least 20,000 h. LED illumination can typically achieve more than 120% of the 1931 CIE color gamut creating much more saturated colors, especially in the red. Plus LEDs offer instant-on operation, have no mercury (like arc lamps), consume less power and run considerably cooler than arc lamps.

All these are powerful benefits, but there are some challenges to replacing an arc lamp with an LED light source. For one, LEDs can be bright, but they are not nearly as bright as an arc lamp. Secondly, this brightness needs to be packed into the smallest possible area. That is just a reality of projection systems since optics must collect this light to focus it on the small microdisplay panel. Adding more and more LEDs in the illumination stage doesn’t work since the light can’t be efficiently coupled into the optical system (the law of *étendue*). The LEDs need to be very bright and very compact. These requirements challenge developers to create LED devices with thermal management and optical-collection systems to meet this need.

Photonic lattice structures

LED developer Luminus Devices, an MIT spin-off company based in Woburn, Massachusetts, created tremendous buzz at CES with the debut of its new LED devices. Remarkably, all of the five public demos at the show of LED-MDTVs were powered by LED chipsets from Luminus. Each chipset comprises separately packaged red, green and blue emitters (figure 2, p17).

The company has developed a new type of LED emitter called PhlatLight, named for the underlying photonic lattice technology, which incorporates a sub-micron structure on the surface of a top-emitting LED. These structures have typical dimensions in the order of $\lambda/5$, so for 400 nm blue light the dimensions are in the order of 0.08 µm. The net effect of the photonic lattice structure is high brightness per unit area, which has now made the commercialization of LED MDTVs a possibility in 2006.

The photonic lattice has a profound effect on LED light emission, enhancing the efficiency of light extraction and producing a narrower beam angle. The lattice generates a horizontal band gap that prevents the photons from traveling through the LED material parallel to the surface. The photons are confined to the vertical direction, and when reflected from a distributed Bragg reflector (DBR) under the light-emitting layer, light is directed upwards. According to Luminus, the result is that about 80% of the photons emitted by the LED exit the surface of the LED into a cone angle of ±60° – this represents a very

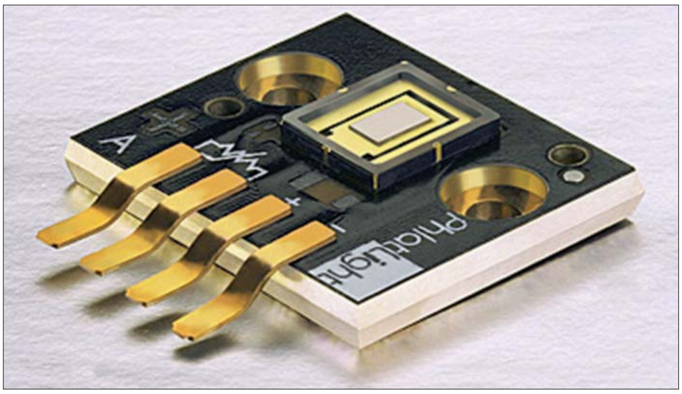


Fig. 2. High-brightness, single-color LED emitter from Luminus.

high extraction efficiency and a real breakthrough.

Bob Karlicek, Luminus' chief scientist, says that the company offers a range of LED emitters, including single and multiple-die emitters with variable die sizes, depending on the needs of its customers. The photonic lattice technology, which is the subject of worldwide patent applications, can be used in a variety of dielectric materials in order to obtain the best possible performance. Luminus performs all operations related to the production of chipsets.

Cost is key

Finally, there is the issue of cost. LEDs for displays need to be the brightest devices on the wafer. But they also need to fall within tight spectral output guidelines. The combination creates a very stringent selection, or binning, criteria. Not only will this increase costs, but it may limit availability of devices. This could end up being a big problem if hundreds of thousands of devices are needed to meet strong market demand for the LED-based MDTVs. Luminus has an added challenge – ramping up its photonic lattice fabrication process to full production and high yield.

Ultimately, the cost of the LED illumination stage of the projection engine needs to be close to the cost of an arc-lamp-based stage. In an LED-based optical engine for DLP applications, separate red, green and blue LED illumination arrays are combined and imaged onto the digital micromirror device (DMD). By using an LED source, designers can eliminate the arc lamp and rotating color wheel, which are used to create sequences of red, green and blue light. With LEDs, the sequencing of the red, green and blue light is not set, as it is with a color wheel, enabling new patterns of illumination. This will help improve performance.

LED light sources can also be used with microdisplay engines that use three images (3LCD or LCOS) instead of one DLP imager. While the duty cycle of the engine is three times as large, the imagers require polarized light, so overall efficiency is about the same as with DLP.

At CES, LED-based MDTVs from Akai, HP, Samsung, JVC and Sanyo were all demonstrated. Akai plans 46 and 52 inch sets with street prices of about $1700–2200, and HP will offer a 52 inch set with a retail price of $2495. Samsung expects to launch its 56 inch RPTV set in May 2006 for $2999 at retail. All will offer the full high-definition (HD) resolution of 1920 × 1080. Sanyo showed an LED-based MDTV based on 3LCVD technology and JVC showed a prototype based on LCOS technology – but neither company has firm plans for commercialization.

About the author

Chris Chinnock is a senior analyst at Insight Media, a market research firm focusing on the technology, markets and business of the display industry. Insight Media has recently completed a major technology and market study on LED and laser-projection systems with the analysis of their impact on seven market segments (see www.insightmedia.info/reports.php).

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Index-matching silicones enable high-brightness LED packages

Silicone materials offer HB-LED designers a number of options for chip encapsulation and lenses thanks to their basic physical properties and customizable optical properties. As **Bill Riegler** and **Rob Thomaier** of NuSil Technology explain, this can help improve the efficiencies and longevity of HB-LED packages.

The ongoing development of high-brightness (HB) LEDs has resulted in high-output devices that have efficacies approaching 100 lm/W and are required to operate at increasingly higher temperatures – for example, the new Lumileds Luxeon K2 device operates at a junction temperature of up to 185 °C. Researchers developing products in this area demand encapsulants and lens materials that function well within the device's operating parameters, and also provide additional optical benefits. Silicone materials can provide the required stability over a wide temperature range, with the added benefit of customized optical properties that provide increased efficiency.

Silicone encapsulants and lenses can be used in virtually any LED package. This article examines the chemistry and properties of silicones that prove ideal for next-generation HB-LEDs.

Polymer chemistry

Silicones, also known as polysiloxanes, are synthetic entities based on the polymer chemistry of alternating silicon and oxygen chains, and have the typical structure shown in figure 1.

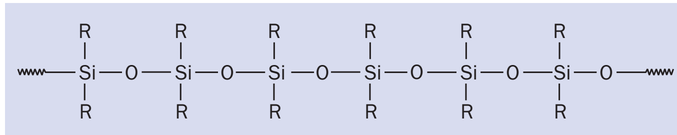

Fig. 1. A typical silicone structure, where R represents a methyl (CH_3) or phenyl (aromatic carbon ring) group.

Various combinations of side groups enable polysiloxanes to exhibit different properties. Alternative material compositions have increased temperature stability (–115 to 260 °C), high optical clarity (refractive indexes as high as 1.60), low shrinkage (2%), and low shear stress. The two polysiloxanes most applicable to the LED industry are described below.

- **Dimethyl silicones**, or dimethylpolysiloxanes, are the silicone polymers most common in industrial use, because they are the most cost-effective to produce and, generally, yield good physical properties in silicone elastomers and gels. For index-matching purposes, all dimethylpolysiloxanes have a refractive index of 1.40, measured at 25 ºC and 598 nm.
- **Phenyl silicones** contain diphenyldimethylpolysiloxane co-polymers. The phenyl functionality boosts the refractive index from 1.40 to 1.60. The amount of phenyl in the polymer determines the refractive index, and can be readily modified to meet a specific refractive index within the range. This modification becomes important when researchers seek to align the refractive indexes of the functional components within the LED.

Material composition

Siloxane polymers form the basis of silicone chemistry, but interactive fillers, catalysts and crosslinking species create the possibility of material compositions ranging from fluids to gels to elastomer systems. This broad range of material composition makes silicone a viable option for an endless number of photonic applications. Some silicone material compositions and their typical applications are described below.

Table 1. Coefficient of thermal expansion values

Adhesive/encapsulant	*Coefficient of thermal expansion (CTE) (× 10^{-6} mm/mm/ºC)*
silicone	300
filled epoxy	70
unmodified epoxy	70

- **Silicone fluids** are non-reactive and reactive silicone polymers formulated with dimethyl, methylphenyl or diphenyl constituent groups, with refractive index values ranging from 1.38 to 1.60. The viscosity of these materials can range from 100 cP (a light oil) to an extremely thick gum polymer. Fluids are typically used to fill air gaps in high-temperature lens assemblies in order to displace dust, permit cooling action or reduce interfacial reflections. They can also be used to fill lenses or microchannel waveguides because of the large thermo-optic coefficient of 2–5 × 10^{-4}/ºC.
- **Silicone curing gels** contain reactive silicone polymers and reactive silicone crosslinkers in a two-part system. When mixed and cured, these materials are designed to have a very soft, compliant feel and will stick to substrates without migrating. Viscosities can be adjusted from 200 to 10,000 cP. Depending on the polymer's functionality, optical index matching can be formulated from 1.38 to1.57. For HB-LED applications, this allows the optimum amount of light to come out of the die, while protecting it from dust, moisture, vibration, and changes in temperature. The yield strength of the gel is low enough to permit wire bonds to slice through it during thermally induced micro-motion, without risking wire-bond failure. →

Table 2. nD of materials in LED production

Material	*Acronym*	*Trade names*	*Refractive index (nD)*
yttrium aluminum garnet	YAG		1.8
cyclic olefin	COC	Topas	1.53
diphenyl-dimethyl-polysiloxanes	PVMQ		up to 1.60
polycarbonate	PC	Lexan	1.59
aluminum oxide	sapphire, ruby		1.76
gallium nitride	GaN		2.5–2.7
aluminum gallium indium phosphide	AlGaInP		3.25

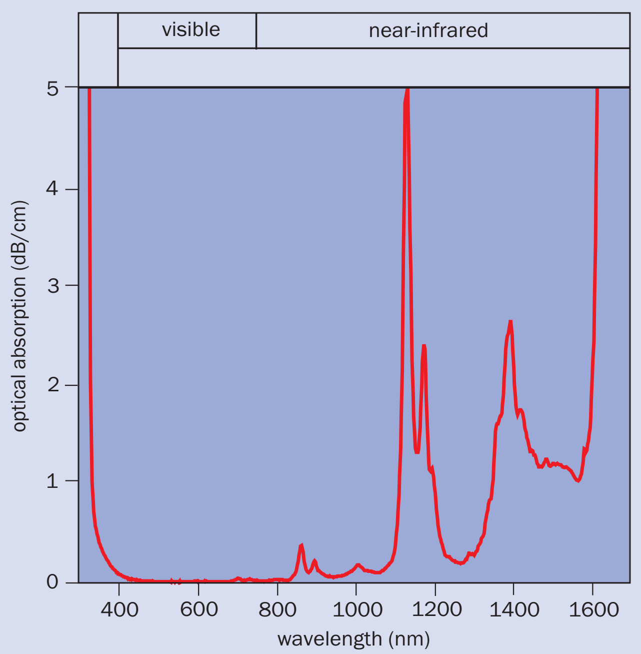

Fig. 2. The optical absorption of a typical silicone encapsulant (LS-6257) in the 300–1700 nm range shows low absorption at visible wavelengths, which is crucial for manufacturers of HB-LEDs.

- **Silicone thermosets** fall into two categories: moldable elastomers and adhesives. Like the gels, these two-part systems contain reactive polymers and crosslinkers that cure up to a rubbery hardness. Most cure at room temperature, although some require heat to cure. To impart increased physical properties, these materials typically have higher viscosities because of longer polymers and reinforcing fillers. Many thermosets are moldable materials that can be cast or injection-molded into HB-LED lenses. They have inherently stronger physical properties than silicone gels and can work as excellent adhesives in optical applications. Silicone thermosets also have the broad refractive index range of 1.38–1.57.

Cure chemistry

While silicones can be formulated with a number of cure chemistries to suit processing or end-use requirements, most curable silicones used in HB-LED applications utilize platinum catalysts. Platinum systems are often cured quickly with heat, but can be formulated to cure at low temperatures or room temperature if necessary. The advantages of these systems include a flexible cure schedule and the absence of volatile byproducts, while the main disadvantage is the possibility of inhibiting the cure, for example through contact with tin, sulfur, and some amine-containing compounds.

Physical properties

For the purposes of this article, we focus on two of the material types – curing gels and thermosets – and describe various physical properties that are important to HB-LED encapsulation and lenses.

- **Coefficient of thermal expansion (CTE)** is the expansion of a cured material per 1 ºC change in temperature. Silicone materials typically have higher CTE values than other adhesive systems such as epoxy, urethane and acrylics. In combination with their low modulus, this allows silicones to act as excellent bridge materials between two substrates with dissimilar CTE values. The junction temperature of certain HB-LEDs can reach 185 °C. Silicones utilized as encapsulants under these conditions impart lower stresses on the surrounding components such as the chip, wire bonds and the lens. Table 1 on p19 lists the CTE values of encapsulants typically used in LED manufacturing.
- **Viscosity** is a standard test to determine a liquid's thickness. This property can become a key factor in the processing and dispensing of encapsulants, and is an important consideration for LED manufacturers when determining process design and equipment requirements.

Optical properties

In addition to the aforementioned properties that include the refractive index range of 1.38–1.57, some silicones are optically clear over the visible range. Key optical properties include refractive index, refractive index vs. temperature, refractive index vs. wavelength, and optical absorption vs. wavelength.

- **Refractive index** is the measurement of the speed of light traveling through a transparent material. To improve device efficiency, the encapsulants and lenses used in the device should closely match that of the epitaxial layer. Refractive index is measured at 589 nm (also known as the sodium D line, or nD) at a fixed temperature of 25 ºC. The refractive indexes of some common materials used in the LED industry are shown in table 2.
- **Refractive index vs. temperature** becomes particularly important as the device's operating temperature increases. The thermo-optic coefficient, the typically reported value from this test, is the change in refractive index as a function of temperature. The test is conducted in 5 °C steps from 25 to 50 ºC at different wavelengths. At 411 nm, for example, a Lightspan encapsulation gel (LS-3252) had a thermo-optic coefficient of -3.92×10^{-4} °C, corresponding to a decrease in refractive index from 1.5443 at 25 °C to 1.5345 at 50 °C. The same gel at 589 nm had a thermo-optic coefficient of -4.07×10^{-4} °C.
- **Refractive index vs. wavelength** data are measured at 411, 589, 833, 1306 and 1550 nm at 25 ºC. For the encapsulation gel mentioned above (LS-3252), the refractive index changed from 1.5443 at 411 nm to 1.5174 at 589 nm, while in the infrared at 833 nm the refractive index was 1.5075.
- **Optical absorption vs. wavelength** is measured across the wavelength range of 300–1700 nm, with 2 nm resolution, using a spectrophotometer with the sample temperature at 25 ºC. Figure 2 shows

that a high-refractive-index silicone thermoset has less than 1% absorption in the visible spectrum where HB-LED emission usually occurs.

Conclusion

The trend in HB-LED design toward higher output has resulted in the need for materials to participate in improving the optical efficiency under heated conditions, and silicones offer the HB-LED designer a number of options for chip encapsulation and lenses. The versatility of polymer chemistry, material compositions, and cure chemistries provide these options. The basic physical properties alongside their customizable optical properties can help improve the efficiencies and longevity of HB-LED packages.

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About the authors

Bill Riegler is the product director of engineering materials at NuSil Technology (www.nusil.com). Riegler has worked in the silicone industry for more than 20 years, holding various positions at NuSil and OSi Specialties Group, the silicone division of Union Carbide that is now owned by GE Silicones. Rob Thomaier is the research director at NuSil Technology. Thomaier has been employed in the silicone industry for 15 years, working in the R&D lab at NuSil Technology.

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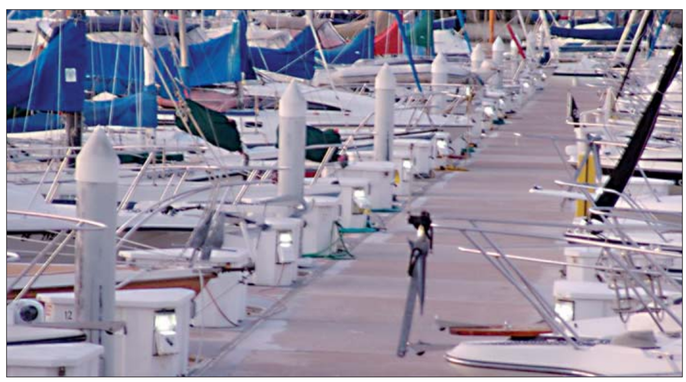

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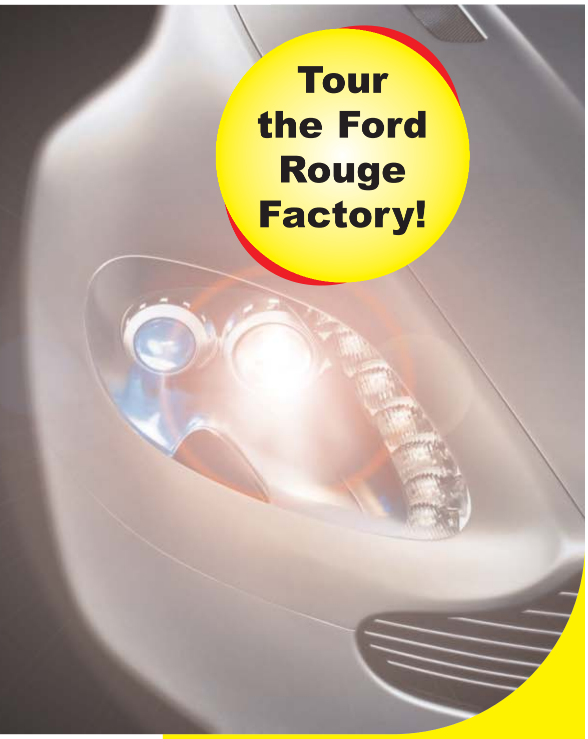

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Interior LED lighting supplies drivers with luxury and comfort

LEDs are one of several technologies that are starting to be used for interior ambient lighting in vehicles, ranging from top-end luxury cars to long-haul aircraft. **Tim Whitaker** reports from the Intelligent Interior Lighting conference, held in Germany in January.

LEDs are already widely used in automotive interiors and have largely displaced incandescent bulbs for the rear illumination of instrument panels and dashboards, as well as for switch indicator lights. At the Intelligent Interior Lighting conference in Munich, Germany, on January 30–31, 2006, the discussion turned to ambient lighting, which is emerging as an added-value feature in high-end vehicles.

There are many potential lighting applications within a car, such as map/reading lights, orientation lights, glove-box lights, luggage compartment lights, map-pocket lights and doorsill illumination. These examples are mainly based on the functional and/or orientation requirements of the driver and passengers, while the trend in future will be to introduce ambient lighting (figure 1). An example is footwell lighting, creating a feeling of comfort and space within the vehicle.

Among the goals for interior lighting are to provide a relaxed, private atmosphere, and to improve comfort and avoid fatigue for the driver. Lighting should help to make large amounts of information readable and clear to the driver, and must not distract or confuse. Ideally, lighting should be programmable and should also adapt for day/night driving and urban/highway/rural environments.

According to Akhila Venkitachalam, senior industry analyst at Frost & Sullivan, the key benefits of interior lighting are orientation, driver safety and differentiation between brands with attractive design in the night-time. Ambient lighting should "appeal to the senses" and "deliver a superior experience" for the driver, she said, although for vehicle OEMs the most important attribute of interior lighting is design.

Robert Isele, manager of perceived value user interface at BMW AG, said that his company creates perceived value through ambient lighting in premium cars, and this is something which customers can see and appreciate every day. Asked whether BMW promotes interior lighting in its marketing efforts, Isele replied, "Not in the past, but it does now." BMW looks to create a homogenous interior for its vehicles, taking into account colors, materials, tactile responses, and of course lighting. "Information systems also have to work with the interiors, to establish a night-time identity – the BMW orange color was first defined in 1986," said Isele.

Manfred Dorn, product interface design manager at DaimlerChrysler AG, emphasized the benefits of ambient lighting for establishing a corporate identity and for providing a customer interface which allows functional elements to be found and used. One example he gave was an illuminated seat-shaped control that adjusts the seat position in the luxury Maybach vehicle.

The new Mercedes-Benz S-Class contains a number of interior lighting features such as the light-guide technology shown in figure 2, p24.

Fig. 1. The car interior of the future? Ambient lighting in vehicles can enhance the driver's comfort and orientation while providing brand identity for the vehicle manufacturer. (Courtesy of Delphi.)

The vehicle also has a "virtual speedometer" – the mechanical gauge has been replaced with a large LCD screen that can also display route-finding information or data from the Distronic radar-based distance-sensing system. The LCD can also show images from the night-view assist system that uses an infrared light source contained within the car's headlamps.

Wolfgang Müller, product manager for light and innovation at Johnson Controls, listed several trends in interior lighting. "One is from functional helper to atmosphere creation – there will be more ambient lighting and also the meaningful combination of several lamps," he said. Other trends include a move from clear optics to translucent materials – "lighting without the lamp" – and from bulbs to LED technology. This is driven by reduced package space, reduced power consumption and the availability of more colors.

There is also a move from single manually operated lamps to "light scenarios", said Müller, which enable optimum illumination in different driving situations.

Technology trends

Most interior-lighting applications (as distinct from backlighting) use incandescent bulbs at present. "LEDs are expected to penetrate interior lighting at a compound annual growth rate of 10%," said Frost's Venkitachalam. Incandescent bulbs are standardized all over the world,

Fig. 2. The ambient lighting in the new Mercedes-Benz S-Class uses the LED modules and light-guides shown in figure 3. Each of the four doors has a light-guide, with one LED module per light-guide. There are two light-guides in the instrument panel: the short light-guide from the steering wheel to the A- pillar uses a single LED module, while the longer light-guide crossing the car uses two LED modules. (Courtesy of Hella and Mercedes-Benz.)

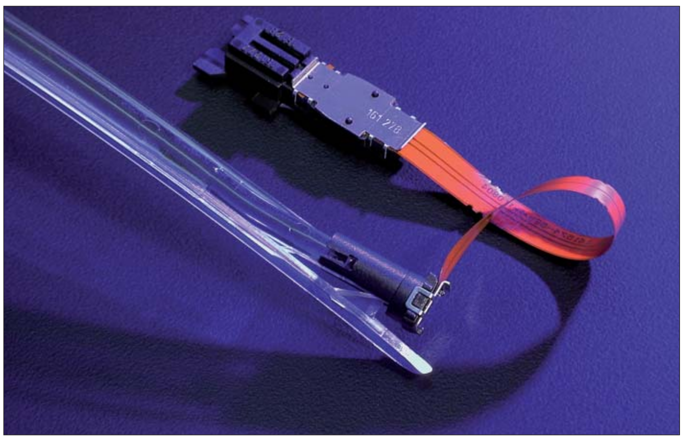

Fig. 3. LED lighting module connected to a light-guide, supplied by Hella for the Mercedes S-Class (see figure 2). (Courtesy of Hella.)

Fig. 4. OVT modules supplied by Hella for puddle and orientation lights on the BMW 7 Series. (Courtesy of Hella.)

and are available at low cost with a wide luminance range. Their major drawback, especially when compared with LEDs, is a short lifetime. LEDs offer good efficiency, design flexibility and the possibility of using new optical approaches such as light-guides. LEDs also have low power consumption and a short response time.

Reinhard Felgenhauer of Delphi Deutschland explained that LEDs meet many automotive requirements. “They are a highly controllable light source with the ability to provide collimated light,” he said. “They have full dimming capability and offer life-of-vehicle performance. Furthermore, they can result in dramatically reduced volume savings of more than 50% compared with bulb solutions, and enable low-profile system design with less than 8 mm height.”

Other light sources are also being used or considered. EL technology, which has been used for backlighting instrument panels, is thin and uniform, although an inverter is obligatory. “Electroluminescent lighting [EL], which provides glare-free and uniform illumination, will achieve 15% penetration of the interior-lighting market by 2015,” said Venkitachalam. Fiber-optic light distribution, on the other hand, will penetrate only the luxury and upper-medium vehicle segments within the same period.

OLEDs, a possible light source for the future, are already being used as displays in some cars. Gunther Haas, OLED program manager at Thomson R&D in France, said that OLEDs struggle to meet the high-temperature requirements in vehicles, although there are no restrictions on after-market products.

Examples of advanced interior lighting products were discussed by Herbert Wambsganß, head of engineering at Hella Innenleuchten Systeme. The company’s first-generation light-guide technology, used for example in the BMW 7 Series, consists of an LED module connected to a linear light-guide from which the light is extracted using prismatic optical structures. Other modules supplied by Hella for the BMW 7 Series are shown in figure 4. A second-generation light-guide is used in the new Mercedes S-Class: six light-guides positioned along the doors and across the dashboard to give subtle interior ambient lighting and a strong brand image (see figures 2 and 3).

Wambsganß also discussed techniques for the dynamic control of ambient light, which adapts the interior illumination to the brightness of the exterior environment and avoids glare and driver discomfort.

Another concept is touchless control using an optical or capacitive sensor to detect a hand movement and switch a light on or off, which would remove the need for the driver to take their eyes off the road. The optical system, with two sensors, detects directional motion and can for example enable a lamp to be dimmed without contact.

Not just cars

Other vehicles are beginning to use LED interior lighting, notably new aircraft from Boeing and Airbus (see DLE to supply Boeing with LED lights for 787). Thomas Knoop of Lichtvision GmbH explained that planes and cars have experienced in the past a technology push from LEDs and other light sources, and are now starting to see a strong application-related aesthetic pull.

Gilles Fourier, a lighting designer at Airbus Central Entity, described light as "a fourth dimension of architectural design", and explained that mood lighting is now being applied to long-haul travel, which promotes passenger well-being as well as providing a certain amount of branding for the airline. Emirates and Virgin Atlantic have made use of LED lighting, while the new Airbus A380 employs LEDs in the cabin, cockpit, cargo and other fuselage areas. The cabin lighting features programmable multispectral LEDs capable of simulating the cabin ambience illumination from daylight to night and various shades in between. Airbus says that the technology is far superior to incandescent light bulbs in terms of brightness and service life. "The airline can choose how it wants to be perceived and what control it wants to have," said Fourier. "Blue light tends to be better in the morning, while red light soothes at night."

Simulation, test and thermal management

Simulation is an important part of designing new lighting systems and accelerates product development, said Gunther Hasna, services and consulting manager at Optis, a France-based software company. "Of course, we need to integrate human vision and the eye response," he said. "For example, there is a difference between day and night vision." For night driving, it is possible to simulate the effect of glare from oncoming headlamps and/or different levels of street lighting.

The standard simulation approach is to build a geometric design using CAD tools; incorporate optical properties of lenses, materials and other components; add the light sources; define the sensors; simulate the system using ray tracing; and analyze the results. "Our system can analyze the driver position using ergonomic tools," said Hasna. "We also use inverse ray tracing to detect glare, and we can incorporate a virtual camera to simulate the eye position when we perform the analysis."

Measuring and testing illumination systems is generally performed using standardized test parameters, but these might not always result in the best yield, explained Matthias Godejohann, VP of sales at Instrument Systems. "The goal is to measure customers' perception, for example the readability of a navigation system, in an economic way," he said. Standard measurements are often based on illuminance and contrast, but experiments indicate there is a level of contrast that the human eye perceives best. "By developing a better model, we could introduce better-adapted specifications, and therefore increase the yield," said Godejohann.

In a space-constrained environment such as an automobile interior, proper thermal management using insulated metal PCBs and heat-sinking can enable arrays of LEDs to be packed more densely, explained Ad Musters, technical director of Universal Science. "In aircraft, where there are pre-defined air-flow patterns, we can design the heat sink accordingly for maximum effect," he explained.

Fig. 5. A prototype roof module incorporates color-changing ambient lighting and LED "stars" embedded in the glass roof. (Courtesy of Delphi.)

LED sources and novel applications

Alexander Ziemer of Nichia Chemical Europe discussed the company's roadmap for high-brightness LEDs and its range of products for the automotive market, which all meet the necessary temperature specifications (–40° to 100 °C) and have in-built protection against electrostatic discharge (ESD) up to 2 kV.

Ziemer also showed a demo of Power Glass manufactured by a German company, Glas Platz. The sample screen contained 25 white LEDs, emitting on both sides and sandwiched between two sheets of glass. The module has a wireless power supply, and current is supplied to the LEDs via a transparent conductive trace which is only visible on close inspection. From a distance the LEDs appear to float within the glass.

Delphi has already applied this product to a demonstration roof module including a "starry sky" formed by embedding LEDs into the sun roof (figure 5). Delphi's Reinhard Felgenhauer explained that the roof concept also incorporates front and rear modules with reading lamps; ambient illumination; lighting around the roof handles and the vanity mirrors; a touch-sensitive roof floodlight; and color-change capability. See LEDs and concept cars at Frankfurt Motor Show for more on Delphi's Flat Wire flexible printed-circuit technology for LED lighting.

Links

Intelligent Interior Lighting was organized by IQPC (www.iqpc.com/transportiq). The company's Automotive Lighting Design and Technologies conference will take place on May 22–24, 2006, in Dearborn, Michigan (see advertisement, p22).

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