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FROM LCD TO SSL—EDGE-LIT LIGHT GUIDES BRING PROVEN TECHNOLOGY TO GENERAL ILLUMINATION • A MODULAR APPROACH TO SSL PLANAR ILLUMINATING FIXTURES • DOES LED LIGHTING HAVE A TIPPING POINT?
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SSL Products and Manufacturing—Winners and Losers

Marc Chason
Editor In Chief

There are winners and losers along value chains when new manufacturing technologies replace incumbent ones. This is no different with Solid State Lighting, and different parts of the value chains are affected in different ways.

In the article “iNEMI 2011 Roadmap for Solid State Illumination” published in the 2012 Winter issue of Global LEDs/OLEDs, a four-level assembly hierarchy for fabricating SSL devices was discussed, and is repeated below. Please see the original article to understand how OLED technology maps into this hierarchy.

Level 0 = Device (LED)
Level 1 = First Level Assembly (LED in Package)
Level 2 = Second Level Assembly (Package on Board)
Level 3 = System Level Assembly (Total System)

Level 0 LED device development has received a preponderance of research interest as the “sexy” technology that drives SSL device efficiency and performance. In parallel, Level 1 and Level 2 assembly processes have been advancing, building upon manufacturing strategies developed by the Surface Mount Technology (SMT) industry for electronics assembly, with some tailoring for unique aspects of certain SSL assembly requirements.

Until recently, Level 3—System Level Assembly, has not attracted the same level of interest as that of the three earlier assembly steps. This is understandable, as the technology needs to be “able walk before it can run”. But now, as SSL begins to “jog”, the research investments made in Levels 0, 1 and 2 are beginning to appear in viable SSL products. As a result of these advances, investments at Level 3 can lead to significant product differentiation.

What constitutes Level 3 investments? Balance of System (BOS) components associated with SSL luminaire assembly can arguably include LED power supplies and drive electronics, which are not required with incandescent devices, while CFL products require different electronic controls than those required for SSL products. Solid State Lighting BOS components can also include new dimming technologies and products. Thermal management schemes, which are also different for SSL luminaires relative to the incumbent lighting technology, can drive new luminaire form factors. Similarly, remote phosphor conversion schemes also open up new product differentiation schemes.

In this issue we highlight technologies from two companies that address Level 3 assembly. Oree and Global Lighting Technologies both make edge-lit luminaire products, and each company provides an article discussing their approaches to manufacturing their planar lighting products.

Our two columnists also address the Level 3 theme in this issue. Jamie Fox of IMS Research provides an assessment of the SSL industry, noting that device cost will control SSL growth. Can advances in Level 3 assembly reduce these costs to enable faster market growth? Or, can Level 3 advances offer new product features that will justify the higher price in the consumers mind?

In his column Kevin Willmorth looks at technology coordination and standards as potential drivers for increased Level 3 impact. This is particularly crucial for manufacturers addressing non-commodity products, where Level 3 assembly can lead to novel product personalization.

As these Level 3 themes play out through product acceptance in the market place, the supply chains and value chains will need to adjust to changing market requirements. As a result, there will be winners and losers, as some incumbent players disappear (or adapt to new realities) and new ones take their places.

—Marc Chason
Focusing on the LED industry

Total solution for LED Manufacturing Process + Technology + Equipment

Panasonic Factory Solutions (PFSC) is part of Panasonic group. PFSC Assembly Technology and Equipment serves the semiconductor & electronics industry worldwide. For more than 50 years, Panasonic PFSC is the leading company for process and assembly equipment for:

- Semiconductor industry (Plasma & assembly)
- Packaging industry (bare die assembly)
- Surface mount technology (SMT)

PFSC now focuses their strategy on the LED market & industry. Process know-how, process development and equipment design & manufacturing help to provide total solution concept for LED-related companies, such as LED makers, LED assembly and automotive companies.

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Newark and element14 launch new LED microsite for design engineers
North American electronics distributor Newark and its element14 engineering community have launched an innovative microsite dedicated to LED lighting technology. The new site at Newark provides engineers with a comprehensive LED lighting destination, offering solution-based guidance for applications such as street lighting, solar power signals and RGB color mixing, as well as access to a wide range of design and collaboration tools.

In addition to application notes, white papers, training resources, design tools, and videos, the new LED site enables engineers to view and purchase from a best-in-class product portfolio available for same day shipping. www.newark.com/lighting

Intematix phosphor blend accomplishes near perfect light quality for LEDs
Intematix Corporation has demonstrated a phosphor blend that provides a near perfect color rendering index (CRI) of 98 and R9 value of 99 when applied to a reference LED package. The results highlight Intematix’s phosphor leadership in the LED lighting industry, as the phosphor blend combines three separate material families, all offered by Intematix. This achievement paves the way for designers to develop LED lighting systems for retail, hospitality, residential and museum locations that greatly enhance the appearance of apparel, environments, skin tones and artwork. www.intematix.com

More than a million Cree LEDs illuminate China’s first major highway LED lighting project
Helping to further drive the LED lighting revolution, China recently completed its largest highway lighting upgrade with more than 10,000 street lights featuring more than a million Cree XLamp® XP-G and XP-E HEW LEDs. The Shenzhen highway project includes nearly 75 miles of roadways, with LED fixtures installed along one tunnel and four highways.

In compliance with China’s stringent roadway lighting requirements for light efficacy, brightness, luminance, heat dissipation and service lifespan, Kingsun Optoelectronic Co. Ltd. selected Cree XLamp LEDs to illuminate Jihe highway number G15, Nanguang highway number G9411, Longda highway number S318, Yanba highway as well as the Dameisha Tunnel. www.creeledrevolution.com

Dow Electronic Materials launches LED technologies business
Dow Electronic Materials announced the formation of a new LED Technologies business segment to capture current and future demand for LEDs in the global SSL market.

In addition to the metalorganic CVD precursors, the new LED technologies business will supply photoresists, related ancillaries for lithographic processing, and pads and slurries for CMP. www.dow.com

Philips Lumileds receives “Best Technology Innovation Award”
Philips Lumileds received three awards for its technology and market work in China over the last year at OFweek’s 8th LED Forward-Looking Technology and Market Seminar and the 2011 LED Industry Outstanding Enterprises & Products Annual Award Ceremony. The company’s awards included Technical Innovation Award for LUXEON A, LUXEON S, and Freedom From Binning, Best LED Application for the Guangzhou TV Tower, lit with LUXEON and Most International Influence Award. www.philipslumileds.com

Samsung Venture Investment Corporation becomes a shareholder in Novaled AG
Samsung Ventures Investment Corporation and Novaled AG announced that SVIC has become a shareholder of Novaled.

“SVIC’s investment confirms the importance of our technology and our specific materials for the OLED industry. Samsung’s shareholding will reinforce our leading position and help serve all our customers better,” says Gildas Sorin, Novaled Chief Executive Officer. www.novaled.com

Manncor pick-and-place assembles 4-ft. long LED light panels
Manncor’s MC-392LED is ideally suited for populating extra-long LED panel assemblies in a single pass. Through the use of the low-cost optional CT-150 Conveyor Extension Unit, the machine becomes capable of two-stage assembly of oversized LED boards of up to 1.2 m (47.25”) long. With its dual-head placement rate of 6,400 cph and long record of reliability in SMD placement, the 392 will meet or exceed production goals. Other features include ball screw X-Y drive and closed-loop servo control with linear encoding for placement accuracy of 30 µm, 3 Sigma. The MC392LED, at $60,000, joins the larger MC-388LED, another Manncor LED-enabled placer with 192 tape feeder capacity, which enables it to assemble LED panels of up to 1.2m (47.25”) in a single pass without the need for a conveyor extension. The MC-388LED is priced at $85,000. www.manncor.com
as director of business development—materials. In his new role, David will be responsible for Christopher Associates' full line of consumable materials for the printed circuit board (PCB), printed circuit assembly, solar and LED markets. David brings more than 25 years experience in specialty chemicals, solder masks, inks and pastes related to the printed circuit board industry. www.christopherweb.com

Rutronik sets up Lighting Solutions Division

Rutronik Elektronische Bauelemente GmbH has set up a Lighting Solutions Division at its headquarters in Ispringen, Germany, in order to offer not only components and application support but also complete LED concepts including design, dimensioning and light ranges through to support including regulations and building inspection. This gives customers helpful access to lighting planners and designers, architects and engineers offering technical support in switching to LED technology and on new LED installations. The team is composed of experts in lighting design in all areas of interior and exterior lighting as well as engineers with special knowledge of regulations, light ranges, software, construction work acceptance and building inspection. www.rutronik.com

Philips increases OLED production capacity in Germany

Royal Philips Electronics is investing EUR 40 million to increase its production capacity for OLED-based lighting at its facility in Aachen, Germany. The investment will support the rapid growth of Philips’ OLED business, with increased availability of Philips OLED modules for high-end design lighting applications for decorative and ambiance creation purposes. The additional capacity at Philips’ OLED facility in Aachen, which was originally established as a pilot production line, is expected to be available in 2012.

Philips also recently opened its Lumiblade Creative Lab in Aachen, inviting lighting designers, luminaire manufacturers and creative minds to get a hands-on experience of OLED light as a material. www.philips.com

European OLED lighting market to reach $1.5 billion by 2016

Industry analyst firm NanoMarkets’ latest report on the OLED lighting market, “OLED Lighting Markets Europe-2011,” says that market opportunities in Europe for OLED lighting will generate $1.5 billion (USD) in OLED lighting panel sales by 2016. German markets and firms will be the largest factor in the European OLED lighting scene, expected to account for one fourth of all OLED lighting sales during the 2011 to 2018 period. After Germany, the U.K. will generate the greatest revenues from OLED panel sales during the forecasting period covered by the report, with almost $210 million in revenues by 2016. www.nanomarkets.net

Nordson ASYMTEK’s jet dispenser for side-view LED manufacturing wins two technology innovation awards

During NEPCON China 2011, Nordson ASYMTEK received both the VISION Award from SMT China magazine and the Innovation Award from Electronics Manufacturing (EM) Asia for product excellence in the dispensing category for its jet dispenser for side-view LED manufacturing. Nordson ASYMTEK’s jet dispenser enables sticky silicon phosphor to be dispensed into extremely small and hard-to-reach cavities for side-view LEDs. www.nordsonasytmek.com

William McDonough named first chief technologist at Permlight Products

Permlight CEO Philip Frey has named William McDonough chief technologist for the company and its associated brands, Brillia” LED Light Engines and Permlight for Signs”. McDonough will direct smart driver concepts and technology development leading to new approaches in LED advancements. www.permlight.com

PhotonStar LED Group acquires Camtronics

PhotonStar LED Group Plc, the British designer and manufacturer of smart LED lighting solutions, has acquired Camtronics Vale Limited for a maximum consideration of £375,000. Based in Tredegar Wales, Camtronics is a specialist contract assembly company, focusing on complex electronic products covering everything from surface mount PCB population to final product assembly, test and distribution. The acquisition of Camtronics will provide PhotonStar with an expanded manufacturing base as it continues to broaden its presence in the LED lighting space. It is expected to be earnings enhancing in the first full financial year of ownership. www.photonstarled.com

Samsung and Evident Technologies enter into LED patent agreement

Evident Technologies, Inc., and Samsung Electronics Co. Ltd have entered into a comprehensive patent licensing and purchasing agreement for Evident’s quantum dot LED technology. This agreement grants Samsung worldwide access to Evident’s patent portfolio for all products related to quantum dot LEDs from manufacture of the quantum dot nanomaterials to final LED production. www.samsung.com

Titan LED lighting company looks to bring its manufacturing to US

Moorpark, California-based Titan LED is looking at sites in Ohio to establish a 30,000 sq ft manufacturing and distribution facility. The company currently manufactures half of its products in Moorpark and the other half in China. The new facility, which is expected to employ 25 at the start, would allow the company to move all of its manufacturing to the US. The number of employees could expand to “hundreds” after operations are underway. www.titanled.net

LG Display, Cree part ways

The Korea Times reports that LG Display has terminated its contract with Cree for LED chips used in LG Display’s flat-screen products. The two companies had signed a deal in January 2009 in which LG Display secured a supply of LED chips and technological support from Cree. LG Display is engaging in a strategy to diversify its procurement channels for LED chips. To that end, the company has also been running a joint venture with Taiwan’s Amtran Technology and the LED packaging house of Everlight Electronics China. www.lgdisplay.com

Count On Tools LED nozzle series wins industry award

Count On Tools Inc., has been awarded a 2011 NPI Award in the category of Automation Tools for its LED Nozzle Series. Count On Tools’ LED nozzle designs are available for any style of pick-and-place nozzle for any OEM or machine type. All nozzles are guaranteed to function properly with the original equipment. www.cotinc.com

www.globalledoled.com
From LCD to SSL—Edge-Lit Light Guides bring Proven Technology to General Illumination

By Brett Shriver, Global Lighting Technologies, Inc.

Abstract

The proven benefits of edge-lit LED-based light guides as BLUs (backlighting units) for LCDs are being leveraged to make the LED light source an integral part of light fixtures in SSL applications. Combined with advances in LED technology, interior light fixtures such as tracers are being designed around LEDs, rather than trying to make the new technology (LEDs) fit into existing fixtures designed for incandescent or fluorescent bulbs or tubes. This increases the utility and appeal of LED-based light fixtures and reduces time-to-market and maintenance costs.

LEDs first became commonplace as a lighting source in the display industry, where they have replaced cold cathode fluorescent lamps (CCFLs) as the dominant backlighting technology for liquid crystal displays (LCDs). CCFLs have been displaced by LED-based BLUs (backlighting units) in virtually every LCD, including smart phones, mobile computing devices, tablet PCs, and even large-screen TVs. According to a survey conducted by LED Inside, the LED research division of TrendForce, the LCD TV market is expected to increase to 70% in 2012 and, according to WitsView, the panel research division of TrendForce, LED TVs’ penetration rate is expected to increase to 65-70%.

However, as Strategies Unlimited pointed out at the February 2012 Strategies in Light symposium in Santa Clara, CA, the demand for high-brightness LEDs (HBLEDs) to backlight LCD TVs and computer monitors can’t continue to escalate forever—there is already an oversupply of LCDs (see Table 1). In the next few years, it is foreseeable that solid state lighting could replace LCD backlights as the main market driver for LED light sources as the demand for energy efficiency increases and incandescent bulbs are phased out. (see Table 1)

The same benefits of HBLEDs that have been accepted by those familiar with the display industry also bring many benefits to general illumination. These include: a) increased brightness with less heat, b) greater uniformity of light, c) longer lifetimes, d) variations in color temperature, e) wide range dimming to suit changing ambient light conditions, f) wider operating temperature ranges, g) lower voltage / less power required, h) no mercury, and i) a thinner light source that is more efficient and easier to integrate into a wide range of designs. Not to mention the greater aesthetic appeal that they enable. Also, LED manufacturers can bin the components for flux, color and forward voltage, while fine binning for brightness and color can also be used to obtain the proper consistency.

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Table 1: Large-Area TFT LCD Shipments 2009-2011 (Units in Millions)
Source: DisplaySearch—Quarterly Large-Area TFT LCD Shipment Report—Advanced LED
**Edge Lighting**

Edge lighting technology takes advantage of the many advances in the LED industry, such as LEDs specifically designed to couple with light guides that are surface mountable, side emitting, thinner and with wide-output-profile. The use of edge-lit light guides, in combination with pixel-based optical light extraction features, has proven highly successful in producing the most efficient, uniform and cost-effective LED BLUs. Companies experienced in using these technologies for LCD backlighting are successfully leveraging them for use in solid state lighting for general illumination applications.

Edge lighting positions the LEDs along the perimeter—or edge—of the light guide, using LEDs that focus the light into a high-performance optical light guide, Figure 1, which extracts, directs and distributes the light as required by the application, Figure 2.

The light guide is a device designed to transport light from a light source to a point at some distance with minimal loss. They are typically made of thermoplastics such as acrylic or PMMA. Light is transmitted through a light guide by means of total internal reflection (TIR).

Edge lighting has made it possible to take existing light guide technology and expand it into a variety of general illumination applications utilizing high efficiency LEDs that focus the light into a high-performance backlight, or light guide. Because the LEDs are located on the edge of the light guide, there is better optical control for color and uniformity, fewer LEDs, better repeatability, and the thinnest possible lighting solution.

Common examples of edge-lit LED-based light guides at work in the general illumination arena include room lighting (ceiling downlights, wall sconces), under-cabinet, splash and desk task lighting, illumination of industrial and commercial enclosures (e.g., refrigerators, etc.), and architectural lighting, as well as in outdoor applications like pathway illumination and pedestrian traffic signs.

These applications were a natural design evolution for edge-lit light guides as they were developed to take light from a point source (i.e., LEDs) and provide uniform distribution of it over large areas. The “large area” has expanded from a cell phone backlight to an LCD TV to illumi-
Companies who are experienced in developing LED-based edge-lit LCD backlighting are leveraging that core competence to make the HBLED light source an integral part of lighting fixtures in general illumination applications rather than a replaceable part to be designed around, reducing the time-to-market and increasing the appeal of LED-based light fixtures in general.

That is not to say that it is simply a matter of taking LED backlights from LCDs and inserting them into SSL applications. LEDs produced for LCD backlighting are specified and tested under different terminology and conditions than what is accepted by the general illumination industry. LED backlights for LCDs are specified using the CIE color coordinates or wavelength. The CIE system characterizes colors by a luminance parameter Y and two color coordinates x and y which specify the point on the chromaticity diagram, the CIE 1931 XYZ color space created by the International Commission on Illumination (CIE) in 1931. LEDs for general lighting fixtures are specified by Color Temperature. Color Temperature is defined in terms of the temperature of a black body at which it emits light of a specified spectral distribution, which is used to specify the color of a light source. It is usually measured in degrees Kelvin (K). IESNA LM79 provides for the total luminous flux, electrical power, efficacy and chromaticity.

LEDs used in LCD backlighting have their life expectancy listed as a half life (L50) value, whereas LEDs in general illumination products generally use an L70 lifetime expectancy—70% lumen maintenance—which corresponds to a 30% reduction from the initial light output. IESNA LM80 covers lumen maintenance measurement for LED packages, arrays and modules.

Now, many LED manufacturers are offering 100 milliamp devices with flat tops and no lens—ideally suited to edge-lit light guides—that have been specified, tested and binned to SSL specifications, including LM79 and LM80, whereas these were previously only available tested to the CIE color coordinates. This has enabled a company like GLT to go from LCD backlighting into the general illumination market.

**Designing Around the LED**

In the past, there has been a lot of work by companies trying to take LEDs and fit them into an old technology, e.g., trying to put LEDs into an Edison (incandescent) fixture base and doing a drop-in replacement. Presently, if you go to Lightfair International, Strategies In Light or any lighting show, you’ll see dozens of companies selling Edison bulb replacements using LEDs. They’re out there, and everybody can buy them, but that’s not where we see the industry going. Long term, we think that the replacement market has a short life expectancy.

Many companies are starting to realize that in order to take advantage of the true benefits of an LED package, they have to design the luminaire to actually work with the LED rather than just trying to take a luminaire that was designed to use a fluorescent tube or an incandescent bulb and shoe-horning an LED into it—and causing

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*Figure 3. The cone shows the illumination distribution from a point source—in this case, a 2 ft. x 2 ft. LED flat panel downlight employing edge lighting technology, with 100 LEDs spaced along two sides of the light guide for optimal light dispersion—at a distance of 1, 2 and 3 meters (roughly 3, 6, and 9 feet) over 4 different color temperatures ranging from warm white (3000K) to cool white (6000K).*
formance of luminaires. System design to really maximize the per-
through the optical and thermal electrical
ery ounce of efficacy from the device level.
more customized solutions to provide ev-
is more sophisticated system design and
into the general illumination market, there
are a retrofit of the entire luminaire rather
than just the light source.
For example, GLT has developed re-
cessed ceiling light designs where they have
worked directly with the fixture manufac-
turers to do a top-down design of the entire
luminaire around the end light source—
the LED. One of the fixtures for which
they’ve seen huge sales growth in the last
year are the industrial 2’ x 2’ troffer-type
replacements. By designing them as the en-
tire fixture to take advantage of the LEDs,
the efficiency has increased significantly.
There are 2x2 foot luminaires that they are
producing with efficiencies greater than 60
lm/W (lumens per watt).
GLT has shown that the luminaire is re-
ally where solid state lighting is going to go
and take off. Because that’s where you can
take advantage of using LEDs the way they
were meant to be utilized as opposed to
trying to cram them into an old light bulb
form factor.
Measuring Efficiency
The edge-lighting approach achieves maxi-
mum efficiency in light dispersion. But
how do you measure efficiency? Customers
don’t necessarily ask about the efficien-
cy of the LED. They ask about the efficiency
of the system.
Where there is a core competence (such
as LCD backlighting) that’s being extended
into the general illumination market, there
is more sophisticated system design and
more customized solutions to provide ev-
ery ounce of efficacy from the device level
through the optical and thermal electrical
system design to really maximize the per-
formance of luminaires.
Towards this end, application efficien-
cy—i.e., the actual amount of light deliv-
ered to the targeted area in relation to the
total light output of the fixture—is the true
measure of performance. It includes:
• luminous efficacy (lm/W)
• the optimal efficiency of the total
  fixture
• ray-angle control
Luminous efficacy, sometimes referred
to as brightness, is measured in lumens per
watt (lm/W), and is a measure of how well
a light source produces visible light. Lu-
mens per watt are calculated based on the
output of light from the final product as
measured within an integrating sphere vs. the
power that is input into the prod-
currently, the base target for most
BLU suppliers is >70 lm/W, as this is the
requirement to achieve Energy Star perfor-
nance on a luminaire.
Luminous efficacy is only one compo-
nent of the luminaire’s total application
efficiency. In order to achieve high appli-
cation efficiency, a lighting fixture must
direct as much of the light to the target
area as possible instead of scattering it in
all directions, focusing on the target area
to avoid wasted light emissions. So it’s not
just about improving the efficiency of the
LED, it’s about improving the optical ef-
ciciency of the total fixture so that the ef-
ciciency that’s quoted by the LED supplier
also equates to system efficiency. It doesn’t
matter if the LED has a 180 degree spread
of light if you’re only going to use 90 de-
grees of that so it’s about creating the optics
to couple the LED properly in the final fix-
ture so that the light that’s actually reach-
ing the end user and in compliance with
the IESNA LM79 standard is as efficient as
possible, as shown in Figure 3.
Specular optics embedded in the light
guide can direct the light in the specific di-
rection desired. As shown in Fig. 4, pixel-
based light extraction technology can be
optimized to deliver light within the accep-
tance angle of the optical system. In order
to reach maximum application efficiency,
the luminaire manufacturer must work to-
gether with each supplier in the system to
achieve the highest possible efficiency. This
includes those responsible for the power
supply, LEDs, drivers, light guide panels
(LGPs) and films. (See Figure 4)
CRI and Cost
The color rendering index (CRI) is very
important to the aesthetic appeal of the
luminaire. CRI is currently the only inter-
nationally agreed upon metric for render-
ing evaluation of color, being a quantita-
tive measure of the ability of a light source
to reproduce the colors of various objects
faithfully in comparison with an ideal or
natural light source. Light sources with a
high CRI are generally considered desir-
able for luminaires where color is critical.
CRIs approaching 100 are being claimed
by some luminaire and backlight manufac-
turers.
However, in GLT’s experience, accept-
able CRI is actually much lower than com-
monly believed. In the luminaires that
they’ve worked on—typically, the lower-
cost luminaires—CRIs are typically 80.
When they get into the higher efficiency,
higher cost products, they get up to about
85 CRI, but the highest CRI that they’ve
specified on any product is around 85.
As in most other things, there is what
people say they would like to have, and
then there is what people are willing to pay
for, and there is often a pretty wide disparity
between the two. For instance, when
GLT shows customers the price differential
between a luminaire with 50 lm/W bright-
ness and a CRI of 80 at a unit cost of ap-
proximately $125, and a luminaire with 60
lm/W and 85 CRI for approximately $175
per unit, many customers have gone to the
lower cost module without much hesita-
tion. For high-volume products, in the real
world, the most important specification is
often price. For example, pricing for GLT’s
UL-certified OL2 Series troffer 2x2 foot
downlight assemblies begins at about $122
each in volumes of 100 pieces, compared to
$45 to $80 per unit for similar conventional
fluorescent troffers. Given the much great-
er lifetime of LEDs and the effective elimi-
nation of costs for re-lamping, customers
have found that to be very competitive.
That brings up another selling point—
maintenance. In a lot of the environments
where customers are considering a retrofit
of LEDs to an Edison fixture, they have to
pay an electrician to come in and change all their ballasts and fluorescent tubes. If they're changing out a fluorescent tube into an LED, it requires replacing the ballast with a power supply. So, at that point, if customers determine that they still have to bring in an electrician to replace the ballast in order to use a retrofit bulb, and it doesn’t make sense from a cost standpoint, it triggers a new fixture designed around the LED rather than a retrofit bulb.

And now, true SSL modules are being developed from the LED level all the way up through the end luminaire manufacturer. And that’s where it needs to be. When those modules start hitting the market, the industry will see some pretty good adoption rates. For example, GLT has a luminaire that sells into the Japanese market where the LEDs alternate between cool and warm color temperatures, as shown in Figure 5. There’s a dimming circuit and a feedback loop and a remote control to change the color of the luminaire anywhere from warm white at 3000 Kelvin to cool white at 6000 Kelvin, and that’s what the end users love about it—they can pick what color they want. They don’t have to have a luminaire on the ceiling where they’re stuck with one color forever. It’s kind of like incandescent fixtures where they can change out the bulb if they don’t like the color that they purchased, but they don’t have to buy new fixtures. (See Figure 5)

There is also an ambient room light sensor built into the product. When you open the window blinds in a room and the sunlight comes in, the circuitry automatically detects the ambient room light and decreases the power to the luminaire so that it maintains an equal level and saves power.

**Summary**

When GLT first started talking to the lighting suppliers, they had the LED suppliers trying to sell them LEDs, the driver suppliers trying to sell them drivers, and light guide companies trying to supply them with light guides, but there wasn’t a single source putting it all together in a system. Moving forward we see lighting companies partnering with the LED, driver and light guide manufacturers to form more of a partnership rather than a supplier mentality. And that’s what needs to happen—everybody getting together and developing a truly efficient system and then presenting that to the market.

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LED technology is ready to take on fluorescent luminaires for office lighting. I would relamp an existing office luminaire with LED tubes to 1% and LEDs cannot do this yet. Fluorescent lamps are a boring solution for office lighting. LED downlights are more efficient than compact fluorescent. Retail lighting is a boring solution for office lighting. T5 luminaires are still the best solution for office lighting. Linear fluorescent luminaires are still the best solution for office lighting. I prefer to use T5/T8 Florescent lamps are expensive for office lighting. Fluorescent downlights are easier to control than LEDs. Fluorescent downlights are a boring solution for office lighting. LED downlights are more efficient than compact fluorescent.
A Modular Approach to SSL Planar Illuminating Fixtures

Dr. Yosi Shani, Chief Technology Officer, Oree

Abstract

Ultra-slim planar illumination is very attractive for applications where a slim “look” is desired or required. Planar illumination can be achieved using a few methods, among which is the attractive modular approach that enables design modularity in addition to high-end performance. A suitable candidate for that task is the Planar Remote Phosphor module, in which high efficacy is achieved by placing the Phosphor layer significantly remote from the heating/absorbing LEDs. The advantages of these Planar Remote Phosphor Modules for ultra-slim planar illuminating fixtures are herein reviewed.

Planar slim displays are all around us: cellular phones, laptops, monitors and TVs, however it wasn’t long ago when those monitors and TVs were bulky and heavy. Those clumsy pieces of furniture were replaced not because of their low performance or high cost, but mainly due to the attractive slim, fresh look of their substitutes. The same trend is happening also in the illumination area. As a result of the availability of slim, attractive illuminating fixtures, new illuminating designs are coming to the market, which customers happily adopt to replace the old bulky solutions. The sense behind both trends (TV and illumination) are customer’s awareness and willingness to pay for attractive decorative designs.

The need for planar illumination came mainly from the slim display industry, which was and is dominated by the LCD technology, in which planar slim backlights as illumination sources are required. However, since these early days, planar illumination has taken its own path and today fixtures, which are not backlight-

Fig. 1—Cnlight’s table lamp based on Oree’s white LightCell™
oriented, have started to appear. Surprisingly, this trend is apparent especially in applications which overall do not intend to be slim at all, however they deliver a “slim look”—see for example the fixtures shown in Figs 1 and 2.

The first planar illuminating systems were not exactly slim and were based on direct illumination; i.e. on an array of LEDs (or fluorescent lamps), a mixing region and a top diffusive layer, see Fig. 3a. Slim illuminating fixtures were introduced by the edge-lit technology in which the LED (or fluorescent) light is coupled to a waveguide through its edge and coupled out the waveguide through its broad top surface, see Fig. 3b. With this technology, fixture thicknesses within the millimeter and sub-millimeter range are achieved. (Figure 3)

An even thinner illuminating fixture—paper-like—is also within reach; this technology is called OLED and it is based on Organic-LED illuminating layers. However, despite the high investment and the comparably long time that OLED technology has been around, it still suffers from performance, reliability and (mainly) cost issues. The OLED technology may be, in the future, the ultimate slim illumination system; however, for many applications the currently-available edge-lit technology is adequate enough, particularly for 3-dimension type decorative elements like those shown in Figs. 1 and 2.

The competition between edge-lit illumination and OLED is a subject for another article; in the following we will focus on edge-lit technology since it is mature, inexpensive, ready for mass production, and is adequate for most decorative illumination systems.

**Edge-lit illumination systems**

Illumination can be separated into two groups: (i) white illumination and (ii) color illumination. Among them the white illumination holds most of the market and is used for illumination and luminance while the color illumination is mainly for (decorative) luminance applications. We will focus mainly on white illumination due to its importance. Color illumination is very similar to white illumination—thus Red, Green and Blue LEDs are introduced and a Phosphor material/layer is avoided.

Edge-lit illumination can be designed using two methods: (i) with packaged LEDs coupled to its edge, or (ii) with LEDs’ bare chips embedded in the waveguides, see Fig 4. Among the two the first approach is more popular due to its simplicity (using packaged LEDs), however the embedded approach is more attractive due to its capability to deliver more light from the LEDs. We will describe the embedded approach; however many of the features described hold also for the packaged LEDs approach. (Figure 4)

White illumination can be achieved in two ways: (i) using a packaged white LED (with phosphor in the package or (ii) using blue LEDs and remote phosphor at the output region, see Fig 5. The first approach (white LED) is more popular due to its simplicity; however the latter approach, the
remote phosphor, has more advantages, as will be described and discussed. (Figure 5)

The Planar Remote Phosphor module (PRP-Module), is shown in Fig. 6 and is described (schematic cross-section) at Fig. 7. Preferably, the PRP-Module is made out of a Phosphor layer and a waveguide which consists of three regions: (i) in-coupling, (ii) mixing and (iii) out-coupling regions. Light emitted from the LED is coupled to the waveguide, at the in-coupling region via the in-coupling optics, and propagates inside the waveguide by means of Total Internal Reflection (TIR). In this way (TIR conditions), the propagating light's loss is minimal and is mainly a function of the waveguide's material loss, which is for most practical cases low, since a low loss polymer is commonly used. The mixing region is a short waveguide region in which the light has multiple reflections in order to populate the entire waveguide cross-section before it reaches the out-coupling region. At the output region the light is coupled out via optical elements to obtain uniform out-coupled light distribution. The Phosphor layer is located above the output region, thus far away from the in-coupling region in which the hot LEDs are placed. The Phosphor layer converts most of the blue LED light to yellow light. Since some of this light is reflected back to the waveguide, a bottom reflecting optical layer is placed at the bottom of the waveguide in order to back reflect it toward the Phosphor layer. This bottom reflector layer is commonly placed outside the waveguide in order to not ruin the TIR condition or increase the optical propagating loss. A white output light is obtained by the combination of the converted (yellow) and non-converted (blue) lights. (Figure 6)

The advantages of the above described remote phosphor configuration are:

- Higher conversion rate from blue light to white light:
  - The conversion is done far away from the LED; i.e. no light is back reflected toward the LED (which absorb the back reflected light). By placing a bottom reflective layer below the waveguide, as described in Fig. 7, this back reflected light eventually find its way back to the phosphor layer—therefore a high conversion ratio is obtained.
  - The phosphor layer is kept away from the warm LEDs thus its temperature is significantly lower and hence its conversion efficacy is higher.
- A built-in Lambertian output light distribution—the phosphor by its diffusive nature distributes the output light and, system-wise, no additional diffuse layer (additional optics) is required, thus reducing system (fixture) optical loss and cost.

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**Fig. 4**—Schematic cross-sections of edge-lit illumination: (a) packaged LED, (b) embedded LED

**Fig. 5**—Schematic cross-sections of white edge-lit illumination: (a) packaged white LED, (b) remote phosphor
Modular approach

There are two ways for building a large illuminating surface: (i) a single monolithic large panel, or (ii) a modular approach in which the large panel is composed of many small tiles, as shown in Fig. 8. For most purposes the first, monolithic, approach is more common since it offers a lower cost solution for the overall system. However the modular approach also has advantages that make it attractive for many applications; these advantages are hereby discussed. (See Figure 8)

(1) The monolithic approach is limited in the number of LEDs that can be integrated, since LEDs can only be placed in its periphery—a space issue and a heat evacuation problem. Thus the modular approach is preferred in applications where very high light output and power is required.

(2) Modular approach is preferred in non-planar fixtures; see for example Fig. 9, since it can be much lower cost to build such a fixture from modular pieces instead of one complicated 3-dimensional structure. More than that, the modular approach is al-

Fig. 6—Oree’s White LightCell™

Fig. 7—A schematic cross section of a planar remote Phosphor LED
A Modular Approach to SSL Planar Illuminating Fixtures

most a must in applications where
the fixtures' mechanic mutability is
required; see for example Fig. 9 and
the table lamp with the butterfly ap-
proach, shown in Fig. 1, in which the
illuminating plates/"wings" angle
can be adjusted by the customer.

(3) A modular approach will be preferred
by fixture suppliers in cases where
they offer customers many designs
while expecting small volume for
each design. An example for this ap-
proach is shown in Fig. 10 in which
decorative lamps, built from rows of
tiles, are shown.

(4) Modular approach has technol-
ogy advantages due to a shorter light
propagation region in each tile:
a. Overall lower optical loss due to
the shorter propagation region
in the waveguide and hence
more available output power.
b. No “dark region at the center”—
this effect is a result of material
“yellowing” over the years. Most
of the optical waveguides are
made of polymer and polymers
tend to "yellow" in time—to
have more loss at the shorter
(blue) wavelength. Even a mate-
rial with a very small “yellowing
index” will suffer from more
loss at its center since, in edge
coupled waveguides, the loss
is accumulated from the edge
(the light source) to the center.
This effect can be significantly
reduced by using the modular
approach in which the propaga-
tion region, at each tile, is sig-
nificantly shorter.
c. Less chromatic dispersion—in
this effect there is color varia-
tion along the tile and the effect
is more significant in large tiles;
i.e. in monolithic configura-
tions. In waveguides the propa-
gation loss is different for each
wavelength (usually more loss at
shorter wavelengths) thus there
is a variation in the coupled out
intensity of each wavelength
along the tile and hence a color
variation. This effect can be
also overcome by using a re-
move phosphor configuration
in which only one kind of wave-
length (e.g. blue light) is used
and all the color conversion is
done at the remote phosphor
layer.

(5) Additional decorative capabilities—
with the modular approach each tile
can be separately controlled; i.e. it
can be given a different intensity or a
different color—thus creating an ad-
ditional decorative effect.
Summary
Ultra-slim planar illumination is very attractive for applications where a slim “look” is desired or required. Planar illumination can be achieved using a few methods, including the attractive modular approach, which enables design modularity in addition to high-end performance. As discussed, a suitable candidate for that task is the Planar Remote Phosphor module in which the high efficacy is achieved by placing the Phosphor layer significantly remote from the heating/absorbing LEDs.
Abstract:
Basic packaging schemes for organic light emitting diode (OLED) displays often incorporate an edge seal or pressure-sensitive/laminating adhesive (PSLA) to limit edge ingress of moisture vapor and oxygen. This article compares acrylic, siloxane and barrier rubber adhesive material options for use in flexible devices in terms of moisture permeability, adhesion and environmental stability. Our findings indicate that barrier rubber adhesive materials are often the best option due to their low moisture permeability, high optical quality and non-yellowing characteristics.

Overview of packaging schemes for OLED devices
The performance of organic light emitting diode (OLED) displays is steadily improving, and examples of these new capabilities were featured at the recent 2012 Consumer Electronics Show. Initial applications have evolved from simple, passive matrix-driven alphanumeric display devices to active matrix camera displays and OLED televisions as large as 55 inches.1 While the key enabler of these advances has improved the active emitting and charge transport materials within the devices, the packaging which protects them from moisture and oxygen has seen significant advancements as well.2 Approaches to the semi-hermetic packaging required by OLED displays have evolved steadily from early rigid glass-to-can and glass-to-glass structures3 to flexible displays on foil or plastic backings.4 With this packaging evolution has emerged the need for changes and understanding of packaging and encapsulation adhesive options. Generally, when packaging an OLED device, either a perimeter/edge sealed or laminated approach can be utilized. Many application-specific variants and combinations of these two basic packaging approaches are known, including those which utilize fillers and desiccant materials, and specific details are available in the literature.5 Perimeter sealing can often best be utilized within rigid devices, which are compatible with the batch process requirements for dispensing and curing typical edge sealants. Thermally fired glass frits which produce hermetically edge-sealed rigid devices require analogous batch processing. Lamination packaging approaches are often used for flexible devices because roll-to-roll processing is desired for lowering production costs and in-line roll lamination of film adhesives is readily achieved, in principle. Flexible laminating adhesives also alleviate many of the technical challenges related to forming a robust, curable edge seal bond which can withstand rigorous flexing.

In either the rigid perimeter sealed or the flexible laminated package, the moisture-sensitive OLED layer is sandwiched between two impermeable substrates. For rigid devices, one or both of those substrates are often glass. Common examples of rigid perimeter sealed packages include glass-to-glass OLED or electrophoretic displays perimeter sealed with UV or thermally curable highly filled epoxies or fired glass frit. For flexible devices, high barrier materials such as thin glass, steel foil or inorganically coated barrier plastics may be used. Various laminated OLED packaging schemes using inorganically coated high barrier plastic substrates with liquid or solid laminating adhesives have been demonstrated.6
Focusing on flexible displays, two fundamentally different packaging scenarios exist. In the first, no other discrete barrier layers exist within the device aside from the impermeable front and back substrates. The barrier performance of the epoxy edge seals used in rigid OLEDs can be considered a minimum criterion for a flexible laminating adhesive within such a device. The presence or absence of desiccant materials in a flexible device will certainly affect this comparison, but for a first order approximation, this will not be further considered here. The perimeter sealed and basic flexible laminated packages are illustrated in Figure 1a and Figure 1b respectively (possible desiccant packet/layers omitted for clarity). In this case, the PSLA is in direct contact with the OLED active material layer, making chemical compatibility with that layer a critical consideration. Excellent optical quality and stability are required for top emission OLED structures in order to allow for high quality viewing through the adhesive layer. Adhesion must be at least as strong as the other layers in the laminate stack. In scenario two, an inorganic barrier layer is deposited over the surface and edges of the active OLED layers prior to lamination of the front substrate with the PSLA. In this case, the laminating adhesive plays no role in inhibiting moisture ingress because the back barrier substrate, in conjunction with the inorganic barrier layer deposited onto the device prior to packaging, meets this need. The laminating adhesive is required for securing the protective front sheet onto the device while absorbing possible impact, but not to stop permeant ingress. Also unlike scenario one, the adhesive does not come in direct contact with the active OLED stack, and the requirements for chemical inertness are technically relaxed to some degree. High optical quality and stability is still a requirement. This second packaging scenario is diagrammed in Figure 1c.

It is important to note that the barrier requirements for edge sealants and PSLA materials which prevent edge ingress (i.e. Fig. 1a and 1b) are very different when compared to the barrier requirements for the top and bottom film substrates. This is due to the longer permeation path length and smaller exposure area for a perimeter sealant vs. a high barrier film/substrate. A benchmark for edge ingress barrier requirements can be taken as the classic glass-to-can perimeter sealed packaging approach which is expected to attain a basic lifetime target of 10,000 hours with <10% loss of brightness at a defined drive current. Typically a desiccant packet or layer is used within the device to eliminate any moisture that could potentially permeate into the device as an added assurance measure for reaching the product lifetime goal. Highly filled UV or thermally curable epoxy adhesives can be taken as a benchmark for such semi-hermetic packages. (See Figures 1a-c.)

**Adhesive material classes for use in flexible laminated OLED packages**

Any materials intended for use in laminated or edge sealed packaging must exhibit several key characteristics. From the above discussion, low moisture permeability is clearly important. Also, the adhesive must be chemically compatible with the other components in the device. For a perimeter sealant, the requirement is often for ultralow outgassing of low molecular weight components. Any lamination adhesive/PSA (Pressure Sensitive Adhesive) that is in direct contact with active layers of the OLED must also demonstrate chemical inertness with those underlying layers. Adhesion and mechanical strength of the bond must meet minimum requirements, but these vary widely with each packaging approach. Perhaps more importantly is the stability/reliability of adhesion during use and accelerated conditioning such as 85 °C/85% relative humidity (RH). Adhesives intended for use on the front of a top emission device must be non-yellowing and exhibit high light transmission, optical clarity and low haze. These optical require-
PSLA adhesive material options for flexible OLED packaging

The key basic physical requirements for OLED packaging adhesives in the three general packaging configurations discussed here are summarized in Table 1. These categories will be used hereafter to assess several PSLA adhesive classes. (See Table 1.) The focus here will now be on pressure-sensitive and laminating adhesives (PSLA) for use in the bonding of barrier films or front sheets to flexible OLED displays or general lighting as shown schematically in Figure 1. Basic comparisons will be made across three representative classes of PSLA materials: acrylics, siloxanes and barrier rubbers. These material classes are represented by the Adhesive Research’s 25 micron transfer film products EL-8154, IS-8026 and EL-92734 respectively.

Permeability vs. Material Class

As described above, the PSA layer in the laminated structure with no inorganic barrier layer on the device (Figure 1b) is required to exhibit good barrier properties which should be similar to those of a perimeter sealant given similar exposure areas and permeation path lengths. The exposure area is defined by the dimensions of the device and the bond line thickness (typically 25-50 microns). The path length is the width of the frame at the edge of device into which moisture can permeate before it affects the active layers, similar to the edge width of a perimeter sealant and approximately 1.2 mm. Data collected using a Moncon Permutran-W 3/33 analyzer for the classes of materials of interest is presented in Table 2. Analyses were conducted at 25 °C/100% RH with other specific conditions recorded as footnotes below the chart. Extensive tables of moisture and oxygen permeability data under various conditions are available in the literature, and the data below is generally consistent with those values. See Table 2

It is evident that for laminated packaging configurations such as that of Figure 1b, the only PSLA resin class which provides similar barrier properties to a filled epoxy is the barrier rubber EL-92734 PSA. This adhesive exhibits lower moisture permeability than a filled epoxy despite being unfilled in this testing. Because PSLA adhesives exhibit low Tg and modulus by design, they offer the benefit of being very flexible relative to a good epoxy perimeter sealant. For devices which incorporate an inorganic barrier layer inside the laminate construction as in Figure 1c, any of the acrylic, silicone or barrier rubber adhesives that could be considered as barrier properties are not critical. Although epoxy-based adhesive films can provide good barrier properties when properly designed, their use within large devices is typically limited by their shrinkage/stress buildup upon cure and tendency to yellow upon long-term exposure to oxygen and UVA (320-400 nm) radiation present in visible light (vide infra).

### Permeability vs. Material Class

**Packaging Approach**
- **Rigid Perimeter Sealed**
- **Flexible Laminated**
- **Flexible Laminated with Inorganic Barrier Coating**

<table>
<thead>
<tr>
<th>Packaging Approach</th>
<th>Moisture/Oxygen Permeability</th>
<th>Adhesion</th>
<th>Optical Properties</th>
<th>Chemical Compatibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid Perimeter Sealed</td>
<td>Good barrier properties needed</td>
<td>High adhesion and adhesion stability required</td>
<td>No requirements</td>
<td>No outgassing of small molecules or water</td>
</tr>
<tr>
<td></td>
<td>Fillers acceptable</td>
<td>Primary structural bond Flexible Laminated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexible Laminated</td>
<td>Good barrier properties needed</td>
<td>Good adhesion required</td>
<td>Optical grade adhesive layer required for top emission</td>
<td>High compatibility needed due to direct contact with OLED stack</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cannot be weak adhesive layer in device</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexible Laminated with Inorganic Barrier Coating</td>
<td>No barrier requirements</td>
<td>Good adhesion required</td>
<td>Optical grade adhesive layer required for top emission</td>
<td>Inorganic barrier layer reduces chemical inertness requirements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cannot be weak adhesive layer in device</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table1. Summary of OLED Adhesive Key Attributes**

Peel strength and stability vs. materials class

The adhesion peel force target can vary widely depending on specific application details, but is often not required to be extremely high. For example, in rigid or flexible laminated packages the adhesion of the PSLA to the OLED stack need only be higher than the adhesion of the organic or inorganic active layer to that substrate. Adhesion stability is often a more relevant property from both a physical bonding and chemical outgassing perspective. For OLEDs, which will be bent or flexed, the PSLA must not creep over time or the display’s edges will debond. In these instances, some level of chemical or physical cross-linking is typically employed to eliminate unwanted creep under ambient and appropriate elevated temperatures. The PSLA classes studied here were compared by measuring peel force and peel stability after 85 °C/85% RH accelerated aging. The EL-8154 (acrylic), IS-8026 (siloxane) and EL-92734 (barrier rubber) PSAs were used to form 1-inch wide laminations between 2 mil polyester film and glass and tested for 180° peel strength per ASTM D3330-83. Samples were allowed to dwell 24 hours under ambient conditions, and then tested initially and after 1-week and 2-weeks of aging at 85 °C/85% RH. The results of this test are summarized in Figure 2. The failure mode for all samples was primarily due to adhesive failure to the glass substrate.

The silicone pressure-sensitive adhesive (PSA) IS-8026 and the barrier rubber
PSA EL-92734 exhibited excellent peel stability under all conditions. For IS-8026, this is expected given the hydrophobicity, high hydrolysis resistance and excellent thermal stability of siloxane-based materials. The EL-92734 barrier rubber is, similarly, a very hydrophobic, thermally and hydrolytically stable hydrocarbon material. As such, it exhibits peel stability similar to the silicone material. The EL-8154 acrylic also performed well, although it appears that peel values may have been beginning to decline more rapidly than the silicone and barrier rubber systems after aging at 85°C/85% RH for two weeks prior to testing. All samples exhibited peel forces which would be acceptable for most barrier sheet bonding and front sheet laminate applications, with the acrylic and barrier rubber materials performing slightly better in initial peel vs. the silicone in this respect. Overall, the excellent peel stability of the siloxane IS-8026 system makes it the most attractive selection for long-term outdoor use; particularly if moisture edge ingress is not critical for the specific application (i.e. an internal barrier layer is present as in Figure 1c). As previously noted, the much higher permeability of siloxanes vs. the barrier rubber system means stable barrier rubber adhesives such as EL-92734 will be favored when edge ingress into the device must be minimized through the PSLA. It should also be noted that the barrier rubber systems are significantly less expensive than silicone adhesives. See Figure 2.

Optical clarity vs. material class
The optical properties of the PSLA films

<table>
<thead>
<tr>
<th>Polymer Class</th>
<th>Moisture Permeability (g-mil/m²/day @ 25°C/100% RH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representative UV cured talc-filled epoxy perimeter sealant</td>
<td>12.4</td>
</tr>
<tr>
<td>Acrylic PSA (EL 8154)b</td>
<td>932</td>
</tr>
<tr>
<td>Silicone PSA (IS 8026)b</td>
<td>1705</td>
</tr>
<tr>
<td>Barrier PSA (EL-92734)c</td>
<td>3.0</td>
</tr>
</tbody>
</table>

(a) Mocon conditions: flow rate=10 SCCM, area=5 cm² (b) Mocon conditions: Celgard 2500 carrier, flow rate=100 SCCM, area=1 cm² (c) Mocon conditions: Celgard 2500 carrier, flow rate=10 SCCM, area=5 cm²

Table 2. Selected Moisture Permeability Data

Figure 2. Peel Strength vs. Material Class and Accelerated Aging Conditions
were evaluated using a BYK-Gardner Haze-Gard Plus. The percent transmission, haze and clarity for the adhesives are summarized in Table 3. A typical percent transmission target for a high end display is >98%. Typical display clarity and haze targets are >98% and <2% respectively as generic guidelines. The three classes of polymers that have been studied are all capable of being used in optical-grade laminations. It is notable that the optical quality achieved is also affected by the choice of liners and coating technique used for a given material, regardless of its inherent optical properties.

**UV stability comparisons**

For top emission OLED displays and lighting, the light emitted from the active material is viewed through the PSLA adhesive. As such, the PSLA must exhibit good optical qualities and light stability. The PSLA classes studied were subjected to accelerated UV aging in a QUV Weatherometer. The EL-8154 acrylic, IS-8026 siloxane and EL-92734 barrier rubber PSA films were laminated to glass slides and exposed directly to QUV 340 nm bulbs. The UV-Vis spectra of the films were obtained initially and at periodic intervals over a 13-week aging period using a Perkin Elmer Lambda 900 Spectrometer equipped with a photodiode detector. None of the PSLA classes showed a significant increase in absorbance in the 400-800 nm range after accelerated UV aging for 13 weeks, which would be indicative of yellowing or chemical degradation. The highest absorbance value above 400 nm for the EL-8154, IS-8026 and EL-92734 were 0.053 AU, 0.055 AU, and 0.078 AU respectively. The maximum absorbance values for the PSLAs were similar to the baseline value for a glass slide substrate, and are attributed mainly to light scattering as opposed to absorbance. Representative UV-Vis data for the IS-8026 silicone PSA at time zero (red plot) and after 13 weeks (blue plot) of QUV exposure is shown in Figure 3. It is notable that EL-8154 utilizes an acrylic polymer which is designed for optical applications, and that many acrylics which contain heteroatom-functional monomers are less UV stable. The aromatic UV curable epoxies were tested and yellowed quickly when exposed to UV wavelengths, and are therefore not deemed optically stable enough to pass rigorous accelerated UV aging. The same is true of aliphatic epoxy systems, although discoloration occurs to a lesser degree in well-formulated systems. If UV filter/absorbing layers are incorporated in front of or in the PSLA layer, the inherent UV stability requirements for the polymer can be relaxed to some degree which is dependent on the absorption profiles of both the filter layer and the PSLA layer. Typical absorbing layers/films, which are still transparent enough through which to view the display, can help to extend the service life of an adhesive, but should not be relied on for complete UV protection. See Figure 3.

**Summary and Recommendations**

For flexible OLED packaging which does not incorporate an inorganic barrier layer within the laminate structure, the PSLA selection quickly gravitates to barrier rubber adhesives due to their much lower moisture permeability vs. acrylics, siloxanes and even most epoxies. The high optical quality and UV stability which can be obtained from these systems make them the material class of choice in most cases. For packaging schemes which incorporate an inorganic barrier layer on top of the active OLED stack and underneath the PSLA and high barrier film, a broader range of adhesive classes can be considered because the barrier properties of the PSLA are, in principle, not crucial. Siloxanes are the highest performance choice in this scenario, but due to their high costs, barrier rubber systems become an attractive alternative along with well designed acrylic systems.

Specific packaging geometries and lifetime requirements will continue to evolve for roll-to-roll manufactured OLED displays and lighting, and so too will the exact composition of optimized edges seals and pressure-sensitive and laminating adhesives for those devices. As requirements for performance characteristics such as flexibility, specific adhesion, barrier prop-

<table>
<thead>
<tr>
<th>PSLA Material</th>
<th>Transmission</th>
<th>Haze</th>
<th>Clarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>EL-8154 Acrylic</td>
<td>100%</td>
<td>0.4%</td>
<td>98.8%</td>
</tr>
<tr>
<td>IS-8026 Siloxane</td>
<td>100%</td>
<td>0.6%</td>
<td>99.0%</td>
</tr>
<tr>
<td>EL-92734 Barrier Rubber</td>
<td>99.2%</td>
<td>1.9%</td>
<td>97.6%</td>
</tr>
</tbody>
</table>

Table 3. PSLA Optical Data
erties, chemical and light stability, and cohesive strength vary from one device structure to the next, a fundamental understanding of what can and cannot be achieved for various material class options is essential for adhesive selection. Given the variety of OLED applications under consideration and commercialization, the best PSLA choice will be dependent upon the specific needs of each application.

About the Authors:

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References
Does LED lighting have a tipping point?

If there is such a thing as a tipping point for LED lighting, it certainly won’t arrive in 2012.

Jamie Fox

The tipping point of a market is reached when a dominant technology or player defines the standard for an industry. There is no denying that there are markets, TVs for instance, where products take off suddenly and dominate the competition. However, the lighting market is an entirely different kind of multi-headed beast where several incumbent lighting technologies with diverse attributes, benefits, and detriments fulfill the needs of different applications. Changes in this market will be slow, both as LED technologies evolve, and as the different applications accept the usage of this new technology.

There’s certainly been no tipping point for LED lighting so far. Growth for the lighting market has certainly varied, with packaged LED growth in general lighting growing from 2006 to 2011 between 25% and 65% a year (as revenue) but never doubling or tripling in one year. That’s steady (so far) rather than smoldering and suddenly exploding. Certain segments did move very fast, for example torches/flashlights in 2006-2009 and outdoor lighting in China in 2009-2010. However, even different applications (and different countries) move at different times. As LED efficiency and brightness steadily increases and cost declines, different sub segments become viable, or even compelling, at different moments. For instance, retail, refrigeration and architectural lighting might be considered compelling for LED already, while LED replacements lamps for fluorescents troffers in offices might be only at the visible stage.

Another factor that limits the possibility of the tipping point is the long lifetimes of the technology to be replaced. Even if LEDs suddenly become compelling, they may not be compelling enough to, for example, persuade a local authority that has recently signed a large agreement for street lights for an alternative technology which is expected to serve them well for 10 years.

So the (eventual) huge growth of LED lighting will inevitably take time. Having said that, there is one application area which dwarfs all the others and that is LED lamps for residential use. This is the holy grail for LED manufacturers who once saw it merely as a speck on the far horizon, but now can finally enjoy it coming squarely into view. If this market starts to suddenly move, then the whole market for LED general lighting, indeed the whole LED market, will really start to see growth rates increase, even surge.

Such a move will not happen in 2012, however. The reason is simple: price. We are tracking LED lamp retail prices every month and at the moment although they are certainly dropping they are not dropping fast (there are some notable exceptions), or at least not fast enough for 2012 to be a big year for LED lamps. Instead it’s a year where they are increasingly filter-
Does LED lighting have a tipping point?

Bulbs on sale today (I will use our February data since we haven’t finished our March data at the time of writing) provide a range of Lumen/Watt values from 30 to 100 with an average of 60 Lumen/Watt. Lumen/$ sees an even wider range from 4 to a few products over 60, with an average of 20 Lumen/$. These are worldwide averages based on sampling over 750 lamp models in 13 countries in our monthly LED lamp retail price tracker report. Also, the trends have not been very fast. Lumen/Watt has only increased from 58 to 60 in 5 months and Lumen/$ has increased from 17 to 20 in that time (September 2011 to February 2012). However we can expect to see more next generation products at Frankfurt Light and Building this April. It is possible that the growth in LED lighting will be kickstarted a little bit by the attention LED lamps win at the show (as well as LightFair in Las Vegas in May), and it will be interesting to see if products are launched at some more aggressive price points. Some LED lamps on sale in stores today actually still have prices that are rather similar to products shown at Frankfurt 2010. A good quality LED light bulb with 500 or 1000 lumens still often costs US$25-50. So maybe we are in a stagnant phase in the first quarter of 2012, and the exhibition season could move things on a bit faster.

Given all this, even by the end of 2012, products won’t be flying off the shelves. We believe that the prices need to fall to single digits before serious penetration will occur. It’s not just the psychological impact (i.e. $9.99 vs. $10.00); it also just happens that this is around the point where the payback arguments make sense. Factoring in energy costs, a $25 LED pays for itself relative to a $0.55 60W incandescent lamp in approximately 34 months assuming 4 hours of use per day and energy costs of $0.11 kWh.

At $10 or less, you can actually calculate a single year payback period. Consumers of course are, for the most part, not going to be literally doing the calculations, but they do have an awareness that a 5W or 10W bulb will cost very little in electricity and weigh less, which is a good advantage. Indeed, if they are going to be wary of the quality of cheaper products if the customer is happy with the quality. But most people in the world today don’t have access to those kind of prices for LED lamps in their local store or supermarket, if they even have any LED lamps in their local store at all.

In any case, we, like some others involved in the industry, think if there is anything approximating a tipping point for LED lamps, it is around that $10 mark, particularly for CFL haters. Figure 2 shows the unit penetration of LED lighting. We see it steadily growing over a number of years, starting from 2013 onwards. For LED manufacturers we think this translates into double digit growth for their whole LED business in 2013 and 2014, compared to a flatter market in 2011 and 2012.

Jamie Fox who holds a BS in Physics and Astronomy and a Masters degree in Nanoscale Science and Technology, is IMS Research Lighting and LEDs Research Director and is focused on the markets for LEDs and other optoelectronic components. Based in the UK, he is the lead analyst for packaged LED shipments and demand. Jamie has been working in the LED area for IMS Research for 4 years, has good relationships with most of the leading LED companies, and has spoken at the San Diego and EuroLED conferences.
Solderless LED socket is easily positioned
TE Connectivity’s RoHS-compliant Type BR socket for quick termination of Bridgelux RS LEDs eliminates the need to design, manufacture and integrate a complex metal-clad printed circuit board assembly into a lighting fixture. It also provides lighting designers with a broad range of LED mounting options, as it can be easily positioned and assembled anywhere in a fixture using simple hand tools. This one-piece connector assembly features TE’s poke-in wire termination method for 18 through 22 AWG solid wires, 18 through 20 AWG pre-bonded wires and 18 AWG stranded wires. Included standoff posts position the solderless LED socket assembly onto the heat sink. www.teconnectivity.com

Everlight introduces high voltage LED series for retrofit lighting applications
Everlight Electronics Co., Ltd., launched a range of high voltage LEDs especially suited for use in solid state lighting integral lamps, aka retrofit lamps. Everlight’s new HiVo series comprises a 1W, 2W and 4W solution. The single chip LED provides a luminous flux of 80 / 100 lm at 48-55VDC in a color temperature of 3000 / 5700 K. The 2W product with two LED chips connected in series achieves 140 lm for 2700 K at 95-111VDC. The 4-chip LED with 275 / 375 lm for 3000 / 5700 K is available for voltages of 95-111V in North America and Asia and 190-220VDC in Europe. All HiVo components are supplied in a ceramic package with dimensions of 3.5x3.5mm for the 1W and 6.0x6.0mm for the 2W and 4W. www.everlight.com

Digi-Key stocks Cree’s LMR4 LED lighting modules
Digi-Key Corporation now stocks Cree’s LMR4 LED light modules in Europe and around the world. The LMR4 modules are designed to simplify the creative process, giving lighting manufacturers more options as they develop LED lighting products. The Cree LED Module LMR4 uniquely integrates driver electronics, optics and primary thermal management, making the compact module drop-in ready. Designed to last 35,000 hours while consuming just 12 watts of power, it delivers 700 lumens at a variety of color temperatures from 2700K to 4000K. www.digikey.com

Cree banishes last century’s lighting with revolutionary LED light bulb
In an industry first, Cree, Inc., has demonstrated the brightest, most efficient, LED-based A-lamp that can meet ENERGY STAR® performance requirements for a 60 watt standard LED replacement bulb. This unprecedented level of performance is the result of Cree innovation, Cree barrier-breaking LED performance, Cree TrueWhite® technology and patented Cree remote phosphor technology. The prototype bulb is dimmable and emits a beautiful, warm incandescent-like color of 2700 K, with a CRI of at least 90. It delivers more than 800 lumens and consumes fewer than 10 watts and has been submitted for third party testing to validate the light distribution, lumen maintenance and performance. www.truewhitelight.com

LED driver enables drop-in replacements for halogen MR16 lamps
Maxim Integrated Products introduces the MAX16840, an LED driver that employs a proprietary architecture to ensure flicker-free, dimmable operation with electronic transformers and cut-angle dimmers. Maxim’s patent-pending approach enables the design of retrofit LED lamps that

New LED modules radiate with an efficiency of up to 102 lm/W
The new 15 and 25 W Mega Zeni models from Sharp are compact, light-weight, economical and extremely bright, while still providing a very high level of light quality. The new models produce a light output of up to 2550 lumen (depending on the module), a luminous flux of up to 102 lm/W and a long service life of 40,000 operating hours at a service temperature of 80°C. Sharp is thus setting new standards in light technology. Measuring 24 x 20 x 1.8 millimetres and with an aluminium ceramic plate as the carrier material, the 15 and 25 W variants offer the perfect solution to a whole range of lighting applications.
can replace halogen MR16s without any changes to the existing electrical infrastructure. This removes an important obstacle to commercial viability, allowing end users to enjoy all the benefits of LED lighting with substantially lower deployment costs. www.rohm.com

ROHM Semiconductor releases infrared LEDs for proximity sensor applications
ROHM Semiconductor introduced a new range of infrared LEDs that are specifically designed for proximity sensor applications. The SIM-040/041ST and SIM-030/031ST surface-mount IR LEDs incorporate IR wavelength technology to deliver 850/870 nm peak output in comparison to other devices that produce 950 nm. The IR LEDs deliver a maximum energy savings of 66% and increased efficiency of proximity sensing. www.rohm.com

iWatt’s high power-factor-corrected digital LED driver IC delivers flicker-free dimming
iWatt, Inc., expanded its family of digital LED driver ICs with a two-stage, power-factor-corrected (PFC), primary-side-regulated, leading- and trailing-edge-dimmable, AC/DC digital PWM controller targeting 120V/230VAC offline commercial and industrial LED lighting applications. Designed for isolated or non-isolated LED drivers used in incandescent replacement lamps including both space-constrained (GU10, MR16) and larger (A, PAR) types, the iW3614 (3W to 15W) incorporates features to assure power efficiency, durability, reduced size and component costs, and flicker-free compatibility with existing wall dimmers worldwide. The chip comes in a low-cost, thermally-enhanced SO-8 package with an exposed pad which allows lower die junction-to-PCB thermal resistance for increased reliability. www.iwatt.com

Opto Diode introduces high power, 30-die, infrared LED array
Opto Diode Corporation has developed the first in a series of high power LED arrays, the OD-850-30-030. The new 30-die near-infrared (NIR) LED array delivers more efficient operation and higher power with a narrow beam angle of 30 degrees. The device has a peak wavelength of 850 nm (min. 840 nm and max. 865 nm) and a total optical power output of 16 watts. Ideal for night vision systems and skin therapy applications, Opto Diode’s NIR light-emitting-diode array is available for shipping in OEM quantities by June 28, 2010. www.optodiode.com

YEG Opto introduces new Seoul Semiconductor Z7 4 W high brightness LED
LED manufacturer Seoul Semiconductor has launched the new Z7 LED, the latest addition to the Z-Power Series. The Z7 is a 4-chip, 4-watt LED that delivers up to 440 lm at 5500 k. A high brightness LED, the Z7 is available in pure or warm white and is packaged on a ceramic PCB offering excellent thermal transfer properties and has a footprint of just 9 x 9 x 3.2 mm. The Z7 is ideal for diverse indoor and outdoor lighting applications that require long life and stability such as street lamps, tunnel lighting, down lighting, architectural, decorative, remote/solar powered lighting and commercial lights. www.yegopto.co.uk

Isolated active PFC off-line LED controller is TRIAC dimmable & needs no OPTO isolator
Linear Technology’s LT3799 is an isolated LED controller with active power factor correction (PFC) specifically designed for driving LEDs from a universal input range of 90VAC to 265VAC. The LT3799 is optimized for LED applications requiring 4W to over 100W of LED power and also compatible with standard TRIAC in-wall dimmers. The LT3799’s unique current sensing scheme delivers a well regulated current to the secondary side without using an optocoupler. This not only reduces cost but also improves reliability. www.linear.com

Harvard expands dimmable LED driver range
Harvard has extended its range of dimmable CoolLED DALI drivers to include 1.2A and 1.4A versions. Harvard’s dimmable LED drivers deliver dimming capabilities across a wide range of output currents, which means users can maximize their energy savings and create different levels of lighting by smoothly dimming LEDs at specific times. The DALI drivers allow customers to use digital programming to set different lighting and ambient levels for displays, thereby maximizing their investment. The 1-10V analogue drivers can be simply programmed with a fixed or variable resistor and deliver high efficiency as well as high power factor. www.harvardseng.com

Bourns launches LED shunt protectors for LED lighting applications
Bourns has rolled out new open LED shunt protection systems for use in LED lighting applications. The Bourns LSP-Series ensures reliability of the LED lighting applications engineered in strings. The addition of a LED shunt protection device to an LED design enables the lights in a string to stay lighted by shunting the current over the LED. The LSP-Series open LED shunt protectors are suitable for various LED lighting applications such as back-lighting systems, lighting fixtures and light bulbs. The LSP-Series include four models, namely the LSP1800BJR-S, LSP1300BJR-S, LSP0900BJR-S and LSP0600BJR-S. www.bournes.com

LED driver makes light usable as a design medium over large areas
dilitronics GmbH presents an innovative driver for controlling LEDs. The MCC16 with ground-breaking characteristics has been specially developed for interior applications. The compact design in combination with DMX, TCP/IP or DALI interfaces and a capability of separately controlling up to 16 LED modules is revolutionary, and opens up completely new concepts for the use of LEDs in interior lighting. Whether workplace lighting, accent lighting for hotels and bars, or flexible area lighting for conference and seminar rooms, demanding individual lighting concepts based on LEDs are now feasible. www.dilitronics.com

High intensity SPNovaLED features RGB technology
DOMINANT Opto Technologies has expanded its SPNovaLED portfolio with the launch of a high intensity SPNovaLED (NMRTB-WSG), a substitute for the currently available NMRTB-USD equipment. The LEDs RGB technology enables individual use of chips in the housing to match and mix any specific color including white to offer uniform distribution of light. The LED has a standard luminous intensity of 4000 mcd for blue, 12,000 mcd for true green and 9000 mcd for red at an operating current of 250 mA. Low thermal resistance of the package and silicone encapsulation enhance the operating life of the RGB SPNovaLED. www.dominant-semi.com
Europlacer launches dual head iineo-II VLB for growing LED assembly market

Europlacer's new iineo-II VLB is designed for the growing LED assembly segment. Many LED commercial lighting applications require long PCBs that exceed 48” in length. iineo-II VLB can process these PCBs under “one roof” at speeds often exceeding 20,000 cph. The iineo design optimizes productivity in high-mix environments, while remaining competitively affordable. The assembler can accommodate PCBs as large as 24”W x 63”L, making it ideally suited for handling LED PCB form factors, particularly industrial fluorescent lighting. Keeping with the Europlacer tradition of protecting its customers' investment, the VLB transport system can be quickly/easily converted from single stage handling to four-stage handling of large, typical sized PCBs (up to 18” x 20”). This capability is unparalleled in the assembly market and will help to differentiate Europlacer technology along with its superior, overall flexibility. www.europlacer.com

Nordson ASYMTEK Spectrum jetting system improves side-view LED manufacturing process

Nordson ASYMTEK’s new jet dispensing system for manufacturing side-view LEDs is capable of jetting 0.1 to 0.2 mm dots through windows as small as 0.4 mm into LED cavities. The Spectrum™ S-920N jetting system automatically maintains a consistent shot weight, thanks to software-managed dispense parameters. Closed-loop dispensing eliminates the need for time-consuming operator adjustment. Unlike multi-headed needle dispensing systems, the Spectrum™ is easier to set up and maintain in production, keeping your process under machine control. The system uses a jet for non-contact dispensing. Unlike a needle, the jet retracts much less for silicone break off and therefore shoots multiple shots faster, increasing speed and throughput. The jet’s small, controlled drops of fluid reach tight cavities consistently and reliably, unlike needles, which have orifices larger than the cavity windows of side-view LEDs. www.nordsonasymtek.com

Count On Tools expands their LED nozzle series

The range of new and potential applications for LEDs in electronics is practically endless. Count On Tools has realized this trend and worked to develop a line of nozzle designs that will allow customers to accurately and consistently place LEDs with its existing SMT pick-and-place equipment. Through cooperation with its customers, Count On Tools has expanded its current offering of custom LED nozzles for American Opto, Cree, Edison Opto, Lumiled (Philips), Luminus (PhlatLight), Luxion (Rebel), Nichia, Osram Opto, Sharp, Seoul Semiconductor (P4) and Vishay. This line of custom LED nozzles allows us to help customers achieve better placement with odd-form components in their machines while saving them money. Count On Tools’ LED nozzle series is available for all types of SMT pick-and-place equipment and tooling. All nozzles are guaranteed to function properly with the original equipment. www.cotinc.com

Juki debuts JX-200LED high-speed placement system for LED applications

Juki Corporation’s JX-200LED is targeted specifically for the LED assembly market. The placement system features new algorithms created for the placement of side- and top-view LEDs, rectangular ferrite chip-type and PLCC-type LEDs, making it the ideal low-cost placement solution for LED chips in fast growing markets, such as laptop computers, LCD backlights and var-
features a new upward looking camera for QFP/QFN lead inspection and BGA ball inspection, as well as 1200 mm board capability with multi-indexing. Additionally, the placement system was designed to be able to support a 31.5” x 14” board size when indexed twice in the machine, and a 47.2” board when indexed three times. With speed in mind, the JX-200LED can place 15,300 chips per hour at IPC 9850 and supports the placement of parts from 01005 to 33.5 mm². The JX-100LED also features an optional tri-colored vision centering system that can be used for placing fine-pitch QFPs, BGAs and QFNs for added flexibility and accuracy. All Juki placement machines come standard with a three-year parts and one-year labor warranty.

www.jukiamericas.com

Two new solder pastes for LED applications
Christopher Associates Inc. introduced two new solder pastes formulated for use in LED manufacturing. The Koki TB48-M741 low melting point lead-free solder paste allows the use of a lower reflow profile and helps reduce CO₂ emissions. Properties include excellent wetting and low voiding characteristics. The Koki SO1X7C48—M500C high-reliability, low Ag lead-free solder paste features a patented formulation that offers highly improved solder joint reliability compared to conventional low Ag solder pastes. Additional advantages include reduced head-in-pillow defects, high solder joint strength, excellent thermal cycling reliability and low voiding. By reducing silver content, materials costs also are reduced. www.christopherweb.com

EV Group addresses fast-growing HB-LED market with new mask alignment system
EV Group’s (EVG) latest addition to its portfolio of products was created to optimize the manufacture of high-brightness light-emitting diodes (HB-LEDs), compound semiconductors and power electronics. The new EVG620HBL fully automated mask alignment system builds on EVG’s field-proven mask aligner platform, adding a high-intensity ultraviolet (UV) light source and five cassette stations—significantly more than competitive offerings—to enable continuous fabrication of devices. As a result, the EVG620HBL delivers unparalleled throughput of up to 165 six-inch wafers per hour (up to 220 wafers per hour in first print mode) with the industry's highest alignment accuracy and yield. The EVG620HBL is available for purchase immediately. www.evgroup.com

Essemtec builds 180 x 50 cm printer for LED lamps, offers turnkey production line
Essemtec has set out to develop an automatic production line for LED lamps. The line consists of a large-format printing system, multiple pick-and-place machines, and a curing or reflow system. The line can produce all lengths of LED tube lamps up to 180 cm, thanks to the new inline screen/stencil printer invented by Essemtec, which has a printable area of 180 x 50 cm that allows a panel for multiple 180 cm tubes to be printed in one run. The machine loads and prints PCBs automatically and forwards them to the pick-and-place system. The inline conveyor system is designed to transport heavy aluminium-based PCBs commonly used for LED products. One or more pick-and-place machines are installed inline to mount LEDs and other electronic components onto the PCB. The MIS software, a development of Essemtec, automatically balances the workload over multiple machines to achieve maximum line output. MIS (Management Information System) has other functions, too, such as quality assurance, consumption, and stock management, as well as the storage of production data for traceability. For curing and soldering of the components onto the PCB, a high-performance reflow or curing system is installed inline. The oven is optimized for the unique needs of large and heavy boards and provides constant process conditions at every position. www.essemled.com

Manncorp pick-and-place assembles 4-ft. long LED light panels
Manncorp’s MC-392LED is ideally suited for populating extra-long LED panel assemblies in a single pass. Through the use of the low-cost optional CT-150 Conveyor Extension Unit, the machine becomes capable of two-stage assembly of oversized LED boards of up to 1.2 m (47.25”) long. With its dual-head placement rate of 6,400 cph and long record of reliability in SMD placement, the 392 will meet or exceed production goals. Other features include ball screw X-Y drive and closed-loop servo control with linear encoding for placement accuracy of 30 µm, 3 Sigma. The MC392LED, at $60,000, joins the larger MC-388LED, another Manncorp LED-enabled placer with 192 tape feeder capacity, which enables it to assemble LED panels of up to 1.2m (47.25”) in a single pass without the need for a conveyor extension. The MC-388LED is priced at $85,000. www.manncorp.com

www.globalledoled.com
International Diary

LED expo 2012
December 14-16, 2012
New Delhi, India
theledexpo.com

Lighting Japan
January 16-18, 2013
Tokyo, Japan
light-technology.jp

Strategies in Light
February 12-14, 2013
Santa Clara, California, USA
strategiesinlight.com

LED China
March 1-4, 2013
Guangzhou, China
ledchina-gz.com

Taiwan Int'l Lighting Show
March 26-29, 2013
Taipei, Taiwan
tils.com.tw

LEDeucation 7
March 20, 2013
New York, New York, USA
dlfny.com

Lightfair International
April 21-25, 2013
Philadelphia, Pennsylvania, USA
lightfair.com

euroLED
June 24-25, 2013
Birmingham, UK
euroled.org.uk

LED Lighting Taiwan
June 18-20, 2013
Taiwan
optotaiwan.com/ledlighting

The LED Show
August 13-15, 2013
Las Vegas, Nevada, USA
theledshow.com

CIOE LED TECH China 2013
September 4-7, 2013
Shenzhen City, China
cioe.cn

LED Japan/Strategies in Light
October 16-18, 2013
Yokohama, Japan
sil-ledjapan.com

Strategies in Light Europe
November 19-21, 2013
Munich, Germany
sileurope.com

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led assembly.

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Applications you are involved in:
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