LEDs in Displays Issue


# Information DISPLAY

February 2009
Vol. 25, No. 02

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# Information DISPLAY

FEBRUARY 2009
VOL. 25, NO. 2


***COVER:** The display industry is witnessing a rapid change in the deployment of LED technology from use mainly in small handheld devices to the illumination source of choice for almost all LCD applications. For example, advances in LED design and fabrication techniques are addressing the technical challenges associated with avionics displays and improving the display of critical information in aircraft cockpits as described in the article beginning on page 10.*


CREDIT: Cover design by Acapella Studios, Inc.

**Next Month in**
***Information Display***

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- Retail Application of Bi-Stable LCDs
- Low-Power Segmented Electrophoretic Displays
- A First Look at Display Week 2009
- *JSID* March Preview


INFORMATION DISPLAY (ISSN 0362-0972) is published eleven times a year for the Society for Information Display by Palisades Convention Management, 411 Lafayette Street, 2nd Floor, New York, NY 10003; Leonard H. Klein, President and CEO. EDITORIAL AND BUSINESS OFFICES: Jay Morreale, Editor-in-Chief, Palisades Convention Management, 411 Lafayette Street, 2nd Floor, New York, NY 10003; telephone 212/460-9700. Send manuscripts to the attention of the Editor, ID. Director of Sales: Michele Klein, Palisades Convention Management, 411 Lafayette Street, 2nd Floor, New York, NY 10003; 212/460-9700. SID HEADQUARTERS, for correspondence on subscriptions and membership: Society for Information Display, 1475 S. Bascom Ave., Ste. 114, Campbell, CA 95008; telephone 408/879-3901, fax -3833. SUBSCRIPTIONS: Information Display is distributed without charge to those qualified and to SID members as a benefit of membership (annual dues $75.00). Subscriptions to others: U.S. & Canada: $55.00 one year, $7.50 single copy; elsewhere: $85.00 one year, $7.50 single copy. PRINTED by Sheridan Printing Company, Alpha, NJ 08865. Third-class postage paid at Easton, PA.





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## editorial

### It's All About Change

It seems that now more than ever the term "change" gets used in almost every sentence and is applied to seemingly every situation. Sometimes change is good; other times it is not. Certainly, the current global economic situation is forcing change on all of us, in the form of job cutbacks, re-organizations, and significant reductions in already frugal corporate spending. Many member companies in the display industry, if they have not already announced staff reductions, are certainly slashing their R&D spending and finding every way possible to preserve capital. The storm, as these things are often referred to, is well under way, and we have no real idea of how bad it will get or when it will pass.

The consumers that fuel our industry are spending much less money on new gadgets, and the industry has done such a good job already in populating homes and workplaces with new technology that we are facing a severe shortage of unmet needs as well as a shortage of disposable income. It may not feel so good to be a display technologist these days. Still, even during this storm, consumers will spend billions on new technology and almost all of it will include a display. Therefore, in the midst of this turmoil, it is important not to lose focus on the core value of technology research and differentiation through innovation. A sad reality is that when an industry reduces its R&D infrastructure, it rarely reverses itself.

It's easily recognized that companies with the highest intrinsic value are those that can truly differentiate themselves in their markets. Having a unique solution appears to be much more recession-proof than image and brand alone.

Staying focused on providing unique technology solutions will be more important than ever because another change is coming as well, a change in consumer behavior that goes beyond mere belt-tightening. As impulse buying drops, consumers will be more selective in their technology choices that include TVs, phones, and monitors and make more considered buying decisions than they have before. In this climate, therefore, we may see a new sorting process where the surviving companies will be the ones who offer newer solutions at lower cost points than their peers. The right solution will not be cost alone but best "value," which is an elusive metric to quantify.

As we all know, the display is one of the most critical differentiators in product selection. Those that truly appreciate this will protect their display know-how and nurture their technology investments to seek greater value in their products rather than spending recklessly on their brand and image. This is a climate in which I think that trade-off will pay off, and I believe there are players in our industry who understand this. So, maybe it's not such a bad idea to be in displays after all.

Continuing our discussion of change, I'm very pleased to bring you this month three articles on the commercialization of LED technology for LCD backlighting, solicited and edited by our highly respected guest editor David DeAgazio. As David explains in his editorial, we're seeing rapid change in the deployment of LEDs, moving from a technology used mostly in small handheld devices to the illumination source of choice for almost all LCD applications. It was less than 5 years ago that the very first concept products were demonstrated and a wide variety of practical implementation problems were recognized. One of the very first LED-backlit LCD monitors to be commercialized was an NEC product designed for the high-end desktop graphics marketplace. NEC's effort was enough to get numerous others excited and to justify significant R&D investment in core devices as well as light guides, mixing films, packaging

*(continued on page 41)*

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## Fate of Plasma Displays in Europe Less Dire than Rumored

"Giant plasma TVs face ban in battle to green Britain," read a headline for an article in the UK newspaper *The Independent*. "EU law could ban plasma TVs," warned another in the online PC Advisor. Right after the New Year, a flurry of such articles appeared in the UK and also in the US.

The articles were in response to an EU initiative currently being drafted by the European Commission and scheduled for release this April. Highlights of the initiative, according to Paul Gray, Director, European TV Research, for display-industry research firm DisplaySearch, include:

- A set of minimum energy efficiency standards for TV sets that set a maximum power consumption limit proportional to screen area.
- A mandatory "eco" labeling system (similar to Energy Star in the States) at point of sale for televisions. These are currently being used in the EU for appliances such as washers and dryers and, more recently, cars.
- A mandatory requirement to reduce standby power consumption below 1 W.

So the initiative, while definitely being crafted to pare down the numbers of non-energy-efficient TVs, is not taking particular aim at plasma technology. "While it makes great headlines," wrote Gray in a DisplaySearch blog entry on January 20, "especially in the Euro-skeptic British press, it's just not true." (http://www.displaysearchblog.com/2009/01/plasma-outlawed-in-europe/)

The EC itself took steps to de-bunk the idea that the EU will ban plasma TVs. The EC posted this on its Web site, The EU in the United Kingdom: "…Sarah Lambert, Acting Head of Representation, said that the Commission has decided to target televisions because sales are going through the roof and certain models take up a lot of energy. 'We are working with manufacturers and other groups such as the environmental lobby, retailers, and small businesses because we are not legislating in a vacuum. The aim is to come up with a proposal that everyone can live with and to provide an incentive to make change in order to accelerate the market penetration of the most efficient technologies,' she said." (http://ec.europa.eu/unitedkingdom/press/frontpage/19012009_en.htm)


*Panasonic's NeoPDP is one example of a technology being used to enable more energy-efficient plasma displays. Image courtesy Panasonic.*

*Information Display* contacted Gray to ask how he thought manufacturers on both sides of the pond should react to the pending legislation. "The good ones have known for a while that there is an energy problem with plasma if they do nothing," he says. "While it is debatable how much more energy plasmas use than LCDs, it's clear that for general uses Plasma does use a bit more."

He cites Panasonic as an example of a manufacturer who has been proactive in this area, with its recently introduced NeoPDP technology. When asked about similar efforts from other manufacturers, he answered, "Panasonic has been very open and shown it very early. But I imagine that anybody with a serious stake in plasma has to be working on it. It is a hurdle that everybody's going to come across in every market."

*— Jenny Donelan*

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## LEDs Are on the March

**by David DeAgazio**

There is just no stopping them. Long the dominant illumination technology employed by the smaller displays used in mobile phones and other portable/handheld devices, LEDs are rapidly displacing fluorescents as the illumination technology of choice for LCDs used in notebook computers, automotive and aircraft-cockpit displays, and even large-sized LCD TVs.

The reasons are clear: LEDs have higher brightness, longer life, a wider operating temperature range and color gamut, better solid-state durability, lower power consumption and voltage drive, wider dimming range, a more compact form factor for increased design and styling flexibility, and, of course, mercury-free RoHS (Restriction of Hazardous Substances) compliance.

And LEDs are getting better and better. New advances in LED fabrication technology are improving light-extraction efficiency, increasing luminance, and reducing power consumption. In addition, LED manufacturers are working closely with backlighting manufacturers to ensure that LED packages, sizes, and emission patterns are optimized. LED backlights are getting thinner, with improved light-extraction efficiency that reduces the number of LEDs required for a backlight and lowers manufacturing costs. Advances in thermal design are providing more efficient ways to conduct heat away from the LEDs to maintain a low LED junction temperature, which is critical to long-life operation of LED-backlighting modules.

These design advances, combined with the superior performance of LEDs, are also beginning to overcome one of the main obstacles that has heretofore prevented manufacturers from implementing LEDs in many applications – cost. In automotive LCDs, for example, the crossover point in price/performance ratio was passed in 2007, with the result that more and more new automotive LCD backlight designs will be LED-based.

LEDs are also adding versatility, color control, and dimming. Light sensors that match what the human eye sees are enabling LED-backlit LCDs to be more sensitive to changes in ambient lighting.

The three LED-based articles in this issue of *Information Display* address many of these exciting new developments from different perspectives. The first article is by Francis Nguyen of OSRAM Opto Semiconductors, a provider of solutions based on semiconductor technology for the lighting, sensor, and visualization sectors, and a subsidiary of OSRAM. Nguyen examines advances in LED design and fabrication technology that are addressing the technical challenges associated with avionics displays and improving the display of critical information in aircraft cockpits.

My own article addresses how LED-based backlight units (BLUs) are utilizing performance advances in high-brightness LEDs in consumer-product displays to meet the ever-increasing demands for thinner displays with smaller form factors, and how advances in light-extraction efficiency and edge-lighting technology are enabling LED BLUs to meet performance demands while using fewer LEDs.

The article by Evan O'Sullivan and Bob Pantalone of Jabil Circuit, Inc., examines the challenges involved in the high-volume manufacturing of large LED-backlit LCDs from the viewpoint of a systems integrator and manufacturer.

I hope you will find these articles interesting, and, well, illuminating.

***David DeAgazio** is Director of Sales Worldwide for Global Lighting Technologies, Inc. (www.glthome.com), a Brecksville, Ohio, company founded in 2000 to develop LED-based edge-lighting technology for the latest generation of flat-panel displays. He can be reached at davidd@glthome.com or at 440/922-4584.*

# president's corner

## Deadlines and Crises

There is nothing like a crisis, or a deadline, to focus one's attention. Tonight is the absolute latest opportunity to generate a column for this particular issue of *ID* Magazine. For the past week, I have been traveling on a consulting assignment and planning for an upcoming SID Board of Directors meeting, and scouting for my next paying job – free time has been scarce! Nevertheless, it's either tonight or not at all for the column, and my muse has decided to return just in time to help save the day.

Deadlines and crises do have a way of focusing attention. When a deadline is several weeks or even days away, there is always the comfort of that hypothetical period in the next day or two when the work will get done. In general, I am pretty good at finally getting things accomplished well before deadline. But sometimes, particularly when life gets busy and commitments get juggled, things come down to the wire. I find it interesting that I almost always find it easier to think clearly with a looming deadline.

Perhaps this clarity is simply related to focus. When the deadline is far away, there are many demands on my time. Work, family, volunteer duties (including SID-related activities such as this column), recreational and exercise opportunities, and sometimes simply being lazy all compete for scarce hours. Which particular demand wins depends on where I am, what I was doing before, whether I am alert or tired, and how creative I am feeling.

All those choices go out the window at deadline. When something is due, or a crisis is at hand, and failure won't do, then it does not matter if you are tired, distracted, or have other pressing matters. You need what you need to do to get the job done. So, for tonight other work is being pushed off to tomorrow, and this column is getting my full attention.

I do not think it is much of a stretch to draw an analogy between deadlines and economic cycles. At the time of this writing, the global economy is still reeling, and companies and investors are scaling back waiting for the situation to settle. For people working in the private sector, times are hard, and resources are scarce. The status quo may no longer be acceptable and changes may be needed to ensure survival. The harm caused by poor decisions can be magnified, though, as there is less room for error in overall bad times. Crises and deadlines call for strong and effective action, and the ability to focus and analyze accurately may be the difference between avoiding disaster or rushing towards it.

This imperative to focus is not so important in good times. When things are good, it is less important to maintain high efficiencies or to ensure that all decisions pass a high degree of scrutiny. If a wrong decision is made, it may not matter so much if company sales and profits are growing. It is easier to let difficult decisions slide or to act quickly without all the facts, as the outcome is probably going to work out in any case.

Does this mean that bad times are good? To the degree that a crisis forces a closer examination of actions, maybe bad times provide an opportunity to clean up past mistakes or move in bold but necessary directions. Of course, a deadline and crisis can induce hasty, stupid decisions as well, and bad decisions in bad times can sink a company.

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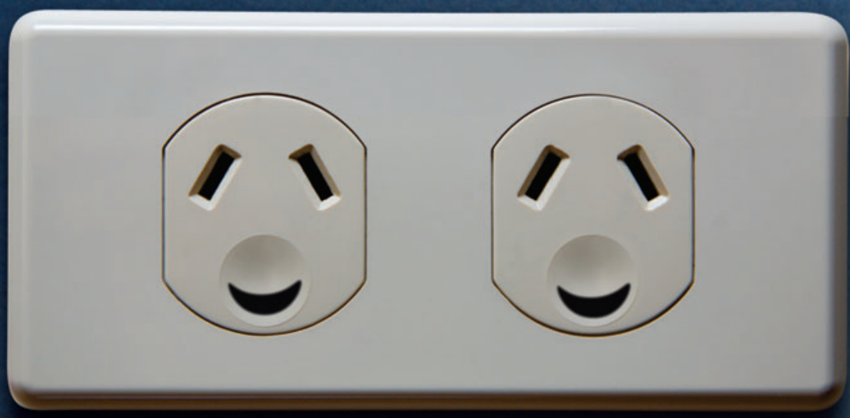

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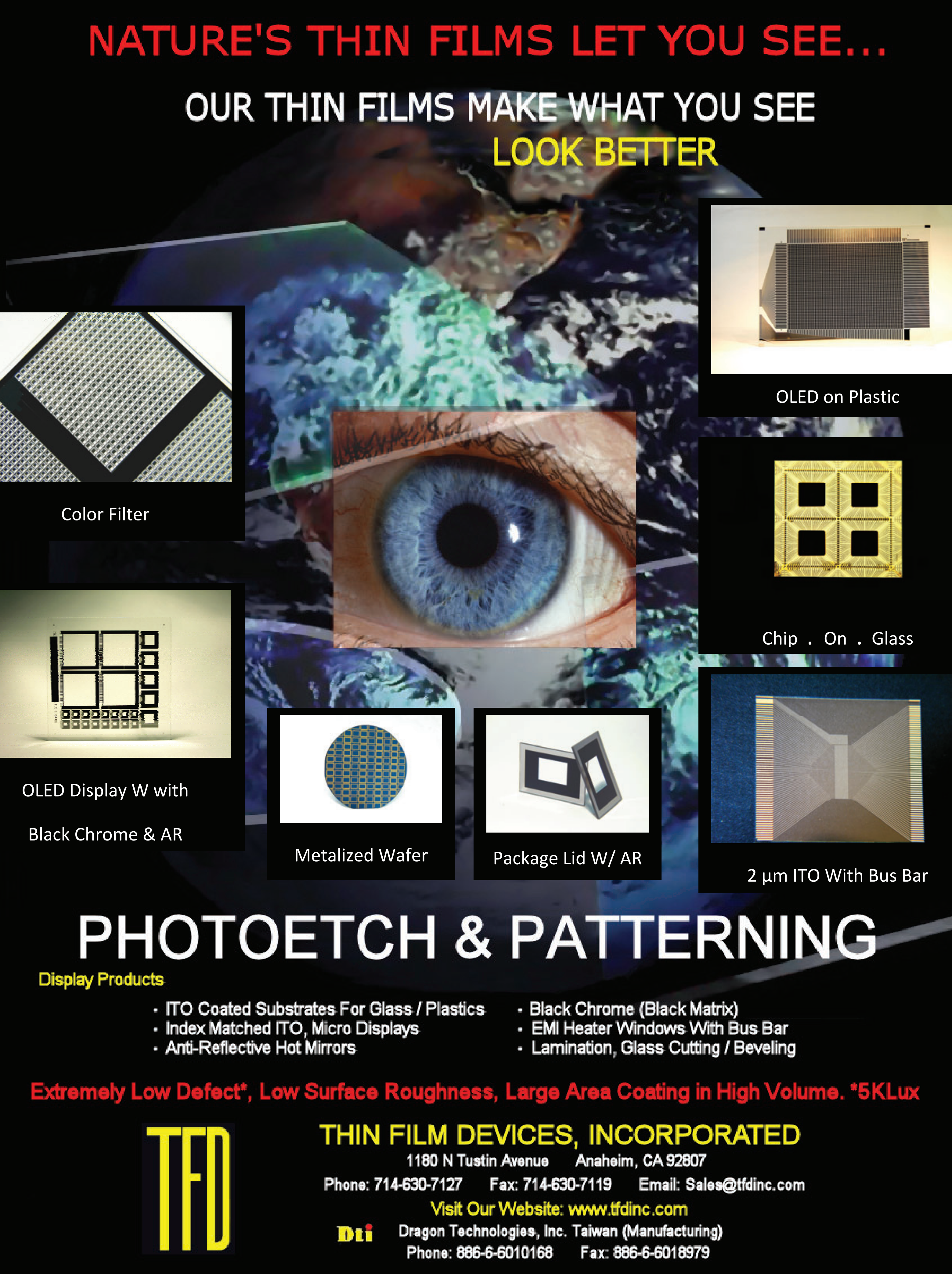
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# Factors Affecting Efficiency and Output of LEDs Used in Display-Backlighting Applications for Aircraft Cockpits

*LEDs bring a new dimension to LCD screens in cockpit applications.*

by Francis Nguyen

ILLUMINATING information displays in aircraft cockpits sounds like a straightforward task. But having the right illumination levels, colors, and display quality means better safety and security when flying 300,000 pounds of heavier-than-air aircraft filled with several hundred passengers. The ability to access information quickly and reliably is critical. Avionics instrumentation has kept pace with the increasing demands for access to technical and operational information in flight, and now LEDs bring a new dimension of light to LCD backlights and indicators for aviation cockpits.

One element of the design of commercial aircraft displays that is sometimes overlooked is the correct level of light. For the human visual system to be able to read displayed information efficiently, it must have the proper balance of light. For best results, this light must meet several criteria, including the appropriate luminance and color spectrum that enhance legibility without causing undue eye fatigue.

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Many aircraft with "glass cockpit" displays – those that use electronic instruments rather than mechanical gauges – still rely on fluorescent lighting for the LCD-panel backlights as well as other light sources, including incandescent lamps. The trend in cockpit design, however, is to move away from fluorescent lighting for LCD-panel backlights and toward the use of LEDs (Fig. 1).

Fortunately, the industry is rapidly integrating solid-state lighting into airliner cockpits and display backlight units. Advances in LED technology give solid-state lighting distinct advantages for aviation applications, such as increased reliability, reduced maintenance, and improved visibility.

### Advantages of LEDs

The avionics industry is well aware of the limitations of fluorescent and incandescent lighting in cockpit applications and is embracing LEDs as the backlighting technology of preference. LEDs address many of the technical challenges of aircraft displays and offer a significant number of advantages compared to incandescent and fluorescent lamps:

- Solid-state robustness compared to incandescent and fluorescent lamps, which have glass envelopes prone to breakage.
- Wide operating temperature range of – 40º to +100ºC. Fluorescent lamps, including cold-cathode fluorescent lamps (CCFLs), typically have a low temperature limit of – 20ºC, which requires a warm-up time before providing any useful light if the aircraft is parked in sub-zero temperatures. This becomes critical for tactical and military aircraft, which require quick take-off.
- Lifetimes of at least 50,000 hours. This compares to a few thousand hours for incandescent lamps often used in backlit switches and indicators. FAA regulations require parts to be changed out at rated life, even before actual failure, resulting in substantial maintenance costs and aircraft downtime.
- LEDs are more efficient than incandescent lamps for applications requiring colored light, such as red and yellow indicators. The colored light is achieved by putting a color filter in front of the miniature incandescent lamps with a resultant efficiency of 1–6 lm/W. On the other hand, indicator-sized LEDs have efficiencies upward of 50 lm/W and they work with and without color filters. LEDs not only reduce power consumption in the cockpit, they also reduce the heat generated by lamps.
- LEDs require a low-voltage DC drive (2.0–3.8 V) compared to the higher volt-



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- age (typically >20 V) for AC drives for CCFLs. Careful shielding is needed to separate sensitive navigation equipment from any EMI generated by the AC drive.
- LEDs are RoHS (reduction of hazardous substances) compliant and rarely require replacement, thus reducing their impact on the environment.
- LEDs provide excellent color saturation and a wide color gamut of over 125% NTSC in LCD backlighting when used in red-green-blue (RGB) combinations compared to the typical 72% capability of CCFLs. The wider color gamut and higher brightness achievable with RGB LED backlights enables the development of multi-function displays (MFDs) that provide brilliant colors so that images can be viewed in sharper detail, even in direct sunlight. This brings new levels of situational awareness, simplicity, and safety to the cockpit with integrated navigation, weather, terrain, traffic, and engine data.

## Wide Range of Lighting Conditions

The biggest challenge for cockpit displays, however, is the wide range of ambient lighting conditions within the cockpit. Cockpit information-display systems have to deliver content at the appropriate light level. For the LCD panels that make up the majority of modern glass cockpit instrumentation, this poses a distinct challenge. Where a typical desktop-computer monitor might have a luminance of 200 cd/m$^2$, a cockpit LCD panel typically needs to produce up to 1000 cd/m$^2$ in order to be readable under high-ambient-light conditions. Because an average LCD panel absorbs about 95% of the backlight output even when showing a full-white screen, this requires an extremely bright backlight.

Typical specifications of an MFD in a modern aircraft require a minimum dimming ratio of 1000:1 (ratio of the brightest setting to the dimmest setting). A CCFL system with careful design in combining an analog control (current only) with pulse-width modulation (PWM) can only achieve a dimming ratio of 300:1 with some risk of causing interference to the display sync signals and audible noise from the power-supply transformer. On the other hand, LEDs with PWM dimming control can easily achieve the necessary dimming range.

## Advances in LED Technology

Advances in LED fabrication technology have led to high-brightness LEDs that provide a wider color gamut and higher efficiency while offering an optimized display brightness-to-thickness ratio. New Thinfilm LED fabrication technology developed at OSRAM is one example of industry advances being made in the area of more-efficient LED light sources. Conventional LEDs have substrates usually composed of silicon carbide, sapphire, or other material. These substrates absorb some


*Fig. 1: Shown is an aircraft cockpit with digital displays.*

of the photons generated by the LED, reducing efficiencies. Thinfilm LED technology emits over 97% of the light from the top surface. Conventional LEDs emit from the four sides besides the top surface, whereas Thinfilm chips are similar to conventional AlInGaP and InGaN wafers, except that they add a sacrificial layer under the epi-layer. The wafer is then inverted and bonded to a germanium substrate with a highly reflective metal mirror surface. Next, the original substrate is lifted off using a laser or chemical etching. The resultant wafer has a Thinfilm active layer that is less than 10 μm thick. Standard processing is then employed to fabricate individual chips with contacts, after which the wafer is singulated into individual LED chips and packaged (Fig. 2).

One example of a high-brightness LED utilizing Thinfilm technology is the new Advanced Power TOPLED Plus (Fig. 3), which also utilizes a new lens specially designed for high efficiency in backlighting applications. At an operating current of 100 mA, these LEDs achieve 14 lm (red), 24 lm (true green), and 28 mW/sr (deep blue). The wider viewing angle of the new lens ensures absolutely uniform backlighting. The chips used are fabricated with ThinGaN and Thinfilm technologies for high efficiency: 65 lm/W (red), 70 lm/W (true green), and 36% overall efficiency (deep blue). CCFLs can achieve similar efficiencies but cannot match LEDs in providing high-brightness (1000 nits) capability.

### More than Flat Panels

There is more to information display in an airliner cockpit than LCD panels. The cockpits are wonders of technological versatility. The same display can be used to show information on different systems, from navigation to engine management, and from radio communications to weather radar. Different types of information are available to the pilots on demand, and when an urgent situation requires it, the aircraft's information system can deliver content to the display for the pilots' attention.

A typical cockpit also has a myriad of switches and indicators that are used to control and monitor the status of many different systems. Information is communicated through the switches and indicators as well. At the most fundamental level, the legends on the switches must be legible in light levels from direct sunlight to nighttime. More than that, the legends and other indicator lights must be visible when they change color, as they do when indicating system status or the position of the control. Urgent conditions are often signaled by a switch legend or a monitor light that changes color. A good solution for illuminating switches and small indicators in applications where multiple changing colors are required is an LED with a small package size, directed light output, integrated reflector, and a homogenous and wide viewing angle.

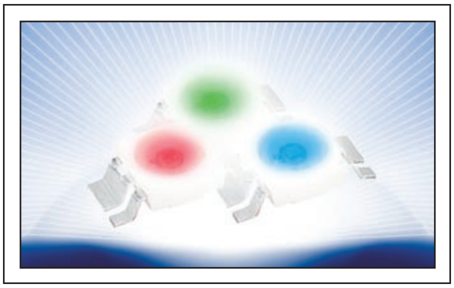

*Fig. 3: Advanced Power TOPLED Plus LEDs have a low profile – 2.25 mm high – that enables the design and production of very thin backlights.*

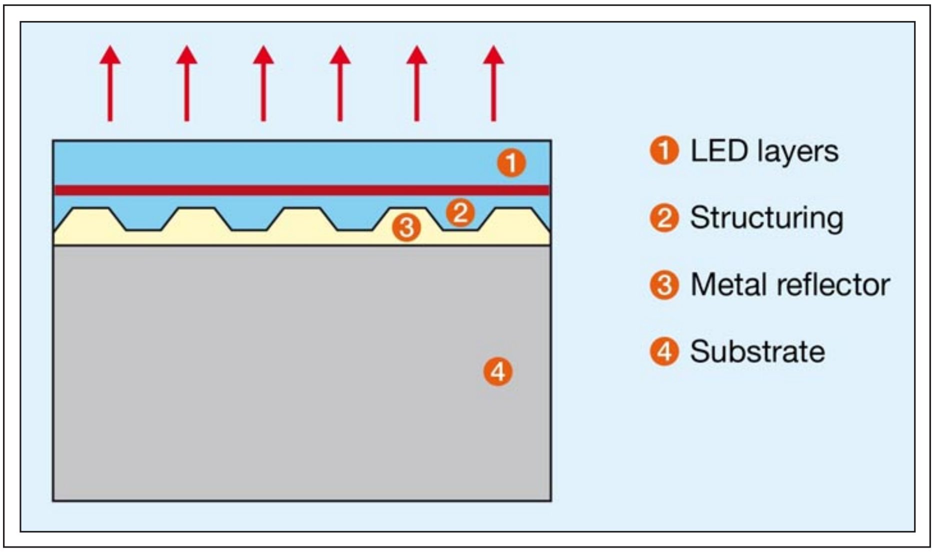


*Fig. 2: The use of Thinfilm LED fabrication technology results in LED chips with smaller form factors and more-efficient light emission than conventional LED devices.*

LEDs are advantageous in switch and indicator applications as well. The low power draw, wide range of dimmable light levels, long life, small form factor, and rugged design all are valuable attributes. In addition, color control is also important, as the hue of the light can be altered for varying conditions. This feature can be especially helpful in choosing a color for cockpit illumination that is least likely to interfere with night vision. Color stability and uniformity emitted from various switches at different brightness settings is important in visual ergonomics, *e.g.*, when a red flag pops up among a sea of yellow indicators and backlit switches.

One other area where LEDs excel over fluorescent and incandescent lamps for cockpit and display illumination is in nighttime surveillance applications (Fig. 4). LED colors can be chosen such that they do not interfere with night-vision imaging systems, whereas fluorescent and incandescent lighting would not work.

### A Bright Idea: Automatic Dimming

Light management within the cockpit is critical to maximize the pilots' ability to gather information from both inside and outside the aircraft. By matching the light output of the information displays to the ambient light conditions, the pilots are able to read instruments and displays quickly and reliably. One challenge is to keep light output at optimal levels without adding to the flight crew's visual load.

An approach to this challenge is to automate the light output, causing displays to be dimmer or brighter based on ambient lighting conditions. This would seem to be a simple task – use a silicon light sensor to detect light levels in the cockpit and adjust the light output of the LCD panels, switches, indicators, and cockpit illumination accordingly. Digital control of brightness settings via PWM can be stored in memory for instant retrieval by the pilot. Automated dimming to maintain optimum ambient light conditions can reduce cockpit-crew fatigue.

However, ambient-light sensing and adjustment are not as simple as they sound. The human eye is sensitive to a relatively narrow band of the light spectrum, generally between 400- and 700-nm wavelengths, which shifts to blue at a lower light level. A typical silicon photosensor is sensitive to a much wider spectrum, starting at about 350 nm and extending well into the near-infrared (IR-A) range to 1100 nm or more. As a result, the silicon device can read light levels that are invisible to the pilots, which could result in the lighting levels being set higher or lower than they should be. A better solution is to use an ambient-light sensor (ALS) that better matches the sensitivity of the human eye (Fig. 5).

Some silicon devices are designed to move the peak sensitivity down to about 550 nm, similar to that of the human vision system. These are far more sensitive to near-IR radiation than human vision, however, and are still subject to significant error.

The optimum solution is a hybrid device that combines an optimized photodiode with an integrated circuit that incorporates signal amplification, a logarithmic converter, and temperature correction. The result is a sensor that most closely matches the performance of the human eye. The curves shown in Fig. 5 compare such a hybrid device (SFH 5711) to an ambient-light sensor, a standard silicon photosensor, and the human eye. The logarithmic amplifier IC enables a large brightness range to be detected with great accuracy without the need for various series resistors. The net result is a solid-state integrated lighting system that adjusts to match the light level needs of the flight crew.

## The Future Is Up in the Air

Industry experts agree that LED lighting is becoming the standard for cockpit-display light sources and will be so for the foreseeable future. LED technology will continue to improve and to migrate into other applications in the cockpit and throughout the aircraft.

*Fig. 4: In darkness, the levels of instrument, control, and interior lighting must be balanced to maintain the pilots' night vision, yet still ensure that all information sources are readily visible.*

Technology advances will continue to increase the LEDs' efficiency, decrease their size, and lower their production cost. This in turn will help make it possible for aircraft-cockpit designers to make improvements to avionics display and cockpit design. For example, by expanding on the multi-functional abilities of LCD panels, expect more

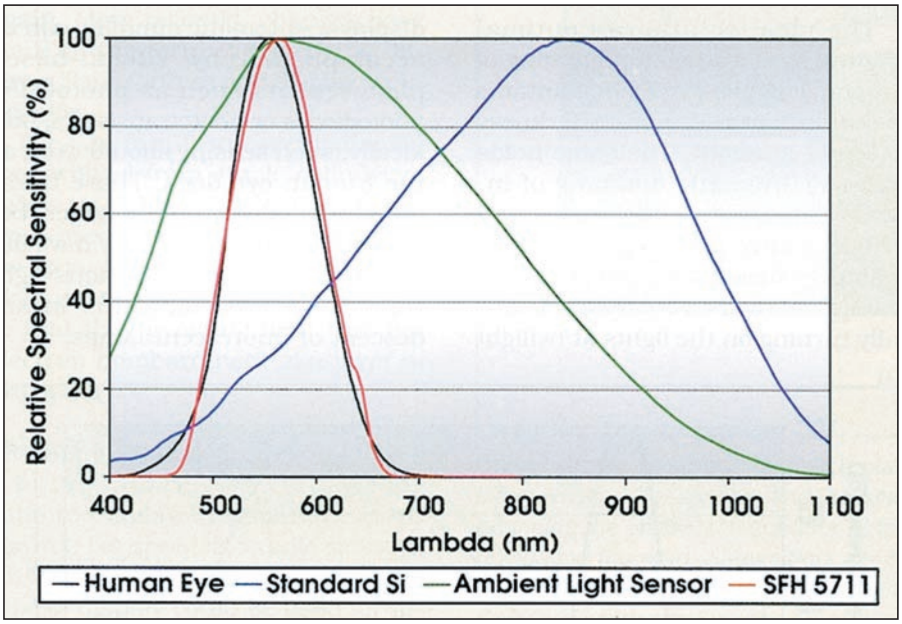


*Fig. 5: Ambient-light sensors (ALSs) most closely match the light sensitivity of the human eye, compared to standard silicon detectors at the same brightness.*

touch-screen technology to be implemented into aircraft cockpits. The versatility of LCD screens will also make it possible to present touch-screen controls for many systems. This will help reduce clutter in the cockpit design by eliminating switches and controls, improving reliability, and encouraging quicker pilot decision-making and response time.

LEDs also can be used in backlights for conformable displays; it may be that curved panels will prove to be more ergonomic and effective at displaying multiple sets of information to the pilots. By making better use of the flight crew's peripheral vision, it may be possible to reduce response times in certain urgent conditions. High-brightness LEDs can also be used effectively for head-up displays (HUDs).

As a result, the role of LEDs in cockpit displays and lighting will continue to expand. Reliable, compact, and efficient, LEDs can help the flight crew stay on top of the many systems involved in getting a flight safely from here to there. ■

# Thin is In: LED Backlight Units Are Becoming Thinner and Brighter to Meet Consumer-Product Requirements

*From mobile phones to LCD TVs, consumer products with LED-backlit displays are demanding ever-smaller form factors with thinner displays, putting the onus on LED-backlight-unit manufacturers to produce slimmer backlights that do more with fewer LEDs. This article explores how to achieve a thinner backlight without sacrificing brightness or uniformity while minimizing the number of LEDs required by the backlight unit.*

by David DeAgazio

CONSUMERS are demanding products with smaller form factors, from slimmer smart phones to thinner LCD TVs. As LEDs continue their march to take over LCD backlighting – migrating from handhelds to larger desktop and notebook displays to 52-in. and larger LCD TVs – backlighting units are getting smaller and, especially, thinner, even as the displays they backlight are getting larger.

Complicating the picture are consumers' desires for more features, particularly in mobile phones and handheld organizers. The mobile-phone industry has responded to these demands. Consequently, these new features have not only led to larger display sizes, they have increased the thickness of some of these units to almost 1 in. – well above the 0.6-in. benchmark of sorts established by the Motorola RAZR back in 2004.

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So the backlight needs not only to illuminate a larger area overall, but to do so with a slimmer, sleeker profile. And, of course, there can be no sacrifice in performance. High-brightness LED-based backlight units (BLUs) that backlight smart-phone displays and LCDs, keypads, and keyboards in a wide array of consumer products, including the latest-generation laptop and desktop PCs and LCD TVs, would seem to be the order of the day.

Optimum light-extraction efficiency combined with improved light-guide BLU designs maximize the advantages provided by the latest advances in LED technology. That means smaller and thinner LCDs and keypads for smart phones and other handheld devices, as well as thinner laptop and desktop PC LCDs, with ultra-thin keyboard backlighting that provides high luminance and uniformity in virtually any color – all with fewer LEDs, meaning less material required and lower manufacturing costs. Backlight assemblies less than 1 mm thick that utilize light guides as thin as 0.4 mm or less are now a reality (Fig. 1).

The result is BLUs of extreme thinness. A backlight for a 2.8-in.-diagonal LCD used in

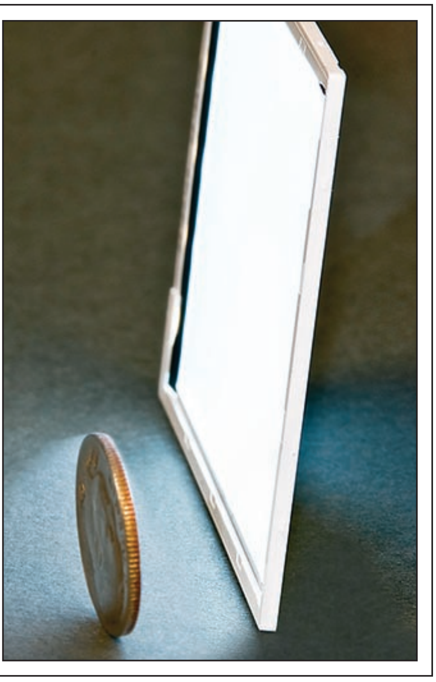

**Fig. 1:** *Backlight assemblies less than 1 mm high that utilize light guides as thin as 0.4 mm or less are now available.*



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a mobile phone today is as thin as 0.4 mm, and getting thinner, with the brightness, efficiency, and cost advantages provided by today's continually evolving and improving LEDs. Proprietary materials, equipment, and processes, including advancements in light-extraction efficiency, are enabling the design of production backlights that are 0.4 mm or less (and 0.3-mm production backlights are close to becoming a reality).

### Moving Beyond Handhelds

As mentioned earlier in this article, LEDs are moving well beyond their established turf in the portable/handheld arena and are making deep inroads into the mid-sized LCDs (3.5–7.0 in. on the diagonal) used in a variety of consumer, industrial, and medical displays and also into the larger LCDs used in notebook computers, desktop monitors, and even flat-panel TVs. Today, designers and manufacturers of these devices are leveraging the advantages of LED backlighting more than ever before: wider color gamut, longer life, DC power with no inverter, lower power consumption, greater design flexibility, a smaller form factor, and lower cost. And, of course, the mercury-free construction and longevity of LEDs make them more environmentally friendly. New BLU design approaches such as edge lighting are amplifying these benefits.

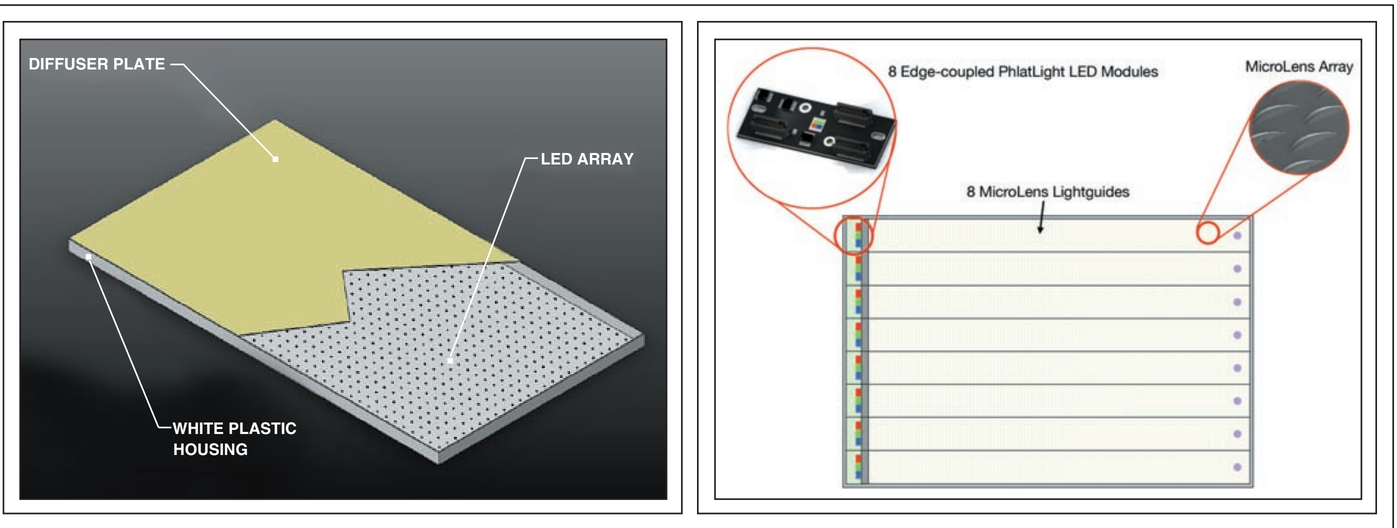
For mid-sized (3.5–7.0 in. on the diagonal) LCDs, designers are confronted with a choice of different LED backlighting technologies. The direct-LED-lighting method, as with all LED-backlighting options, eliminates noise and the need for an inverter – which allows the device to run directly from batteries and provides more design flexibility. It employs top-firing surface-mounted non-focused (120° viewing angle) LEDs in a white plastic tray [Fig. 2(a)], with a thick diffuser plate located at 10–20 mm above the LEDs. With this approach, the brightness is very good – direct lighting provides excellent efficiency and the brightest possible backlight because it is not necessary to bend the light (as it is with edge lighting). However, since there is little or no way for this technique to channel the light uniformly, designers need to add more and more LEDs to achieve a thin backlight with good uniformity.

Uniformity at the surface of the backlight is dependent upon the number of LEDs plus the distance of the LEDs from the diffuser plate. The larger the area, the more LEDs are needed. In addition to the diffuser plate, a designer can use diffuser and prism films to maintain uniformity, but will sacrifice thinness.

For an LCD with a viewing area of, for example, 0.62 × 2.5-in., as many as 36 LED chips may be needed. In larger displays, such as those used in LCD TVs, the LEDs needed for direct illumination will number in the thousands – a possibly expensive proposition.

A preferred approach is to use a smaller number of widely spaced high-output LEDs for edge-lit LED backlighting, but the attainment of brightness and uniformity is much more challenging and requires a great deal of optical expertise. Edge lighting employs side-firing LEDs that focus the light into a high-performance light guide. There are several edge-lighting light-extraction technologies: printed, etched (using chemical, laser, or other means), stamped V-groove, and pixel-based (see Table 1).

Printed, chemical, and laser-etched are diffuse light-extraction technologies. Light is scattered in all directions (360°). Brightness is from low to medium for most applications, output angles cannot be controlled, and non-transparent dots block a significant portion of light that is scattered downward from reflecting back through the panel and exiting the top surface. V-groove offers the benefit of high brightness, but is limited in that 2-D uniformity correction (side-to-side uniformity) is not possible. A specular light-extraction technology such as GLT's MicroLens™ provides high brightness and reflects and transmits light from the optical features in a specular




(a) (b)

*Fig. 2: (a) LED arrays are very high in brightness and typically consist of a matrix of LED chips mounted in a white plastic frame on the PC board behind the LCD. In larger displays, such as those used in LCD TVs, the LEDs needed for direct illumination will number in the thousands. (b) Using edge lighting coupled with MicroLens and PhlatLight technologies, a 46-in.-diagonal LCD TV that requires thousands of LEDs using direct lighting with LED arrays can be backlit to the same brightness using eight PhlatLight chipsets, each containing only three LED chips.*

**Table 1: Comparison of edge-lighting methodologies**

| Technology | Efficiency | 2-D pattern possible |
|---|---|---|
| Printed dots | low | yes |
| Etched dots | good | yes |
| V-grooves | very good | no |
| Pixel based | very good | yes |

manner. With this technology, 2-D uniformity corrections are possible, optical features are transparent, normal reflection and transmission percentages are roughly 60% and 40%, respectively, and the angles at which light is emitted from the light guide can be controlled.

Because the LEDs are located on the edge of the light guide, the approach offers benefits that include better optical control (especially for color and uniformity), fewer light-management film layers, fewer LEDs, better repeatability at all levels, reduced power consumption, and the thinnest possible LED backlighting solution.

### Examining Edge Lighting

A typical direct illumination technique for a 46-in.-diagonal LCD TV will involve thousands of LEDs, requiring from 2000 to 4000 LEDs to achieve a brightness of 8000 cd/$m^2$ at the surface of the backlight. This technique generally employs lower-power less-expensive LED chips.

One example of an edge-lighting technique employs edge lighting coupled with MicroLens and PhlatLight technologies ("Phlat" refers to photonic lattice chipsets developed by Luminus Devices). With this approach that 46-in. LCD TV can be backlit to the same brightness as above using eight PhlatLight chipsets, each containing three LED chips, or a total of 24 LEDs [see Fig. 2(b)].

Edge lighting requires that the LEDs be positioned on the edge of the light guide rather than behind the entire display. This approach offers benefits that include better optical control, fewer light-management film layers, fewer total LEDs, and the potential for reduced power consumption. With this approach, the backlight thickness can be as thin as 0.4 mm.

One of the key drivers to thinner light guides are the ongoing advancements in LED-fabrication technology, which include continually higher brightness, better color, more efficiency, and smaller sizes. To maintain optimum efficiency, the light-guide thickness should be mated to the height of the LED. As LEDs become smaller and shorter (in height), the thickness of edge-lit light guides will continue to decrease. Edge-lit LED light guides rely on total internal reflection (TIR) to propagate the light down the length of the light guide. However, as light guides become thinner, they become inherently less efficient, especially as the size (area) of the light guide increases. These new thinner light guides must utilize the latest advances in optical light-extraction technology to counter this effect.

One solution to this challenge is the pixel-based optical-light-extraction technique previously referred to (MicroLens) in which light-extraction featrures are directly molded into the top and bottom of the light guide and micro-optical elements efficiently extract light at each pixel. This technique provides precise control over six key variables:

- ***Depth:*** Controllable to within ± 2 µm, permitting a high degree of control throughout the panel.
- ***Shape:*** The angle of the reflective surface can be chosen to customize the angles that the light rays exit the light guide.
- ***Density:*** Can be continuously and precisely varied to maximize brightness and optimize uniformity in two dimensions, enabling the design of 180,000 unique shapes per square inch.
- ***Randomization:*** Can be introduced to reduce moiré or other undesirable visual effects and orientation.
- ***Top Shapes:*** MicroLens or other light extracting features can be populated on the top (exit) surface of the light guide to maximize brightness as much as 30%.
- ***Orientation or Angle/Rotation:*** Light-extraction features can be distributed, arranged, and optimized to work with almost any light source location – even in corners.

This approach provides enhanced brightness (to 15,000 cd/$m^2$ and above), crisp color, extreme thinness, less power consumption, and a smaller form factor with fewer components. It also generates a very tight color consistency because light is "mixed" within the light guide. Industrial designers tend to appreciate the design flexibility that comes with having the LEDs located along one edge of the light guide, and this also enables passive thermal management that can be localized and, therefore, simplified. The key is light-extraction efficiency, and that can translate into higher luminance with same number of LEDs, or the same luminance with fewer


***Fig. 3:** This light guide lights nine discrete areas of this thermostat: the main LCD area, characters and directional symbols at the top and sides of the unit (A-F), and keypad buttons with "halo" effect at the top and bottom (G and H).*

LEDs, or the same luminance with the same number of LEDs with lower power consumption.

Edge-lit backlighting allows for color mixing within the light guide. This not only minimizes the LED-to-LED deviations, which can be evident in the direct-lighting approach, but also makes edge-lit guides very adaptable to multi-functional displays. The molded light-guide technology makes highly efficient use of white LEDs, so designers can use fewer LEDs and reduce costs.

### Selective Backlight Illumination

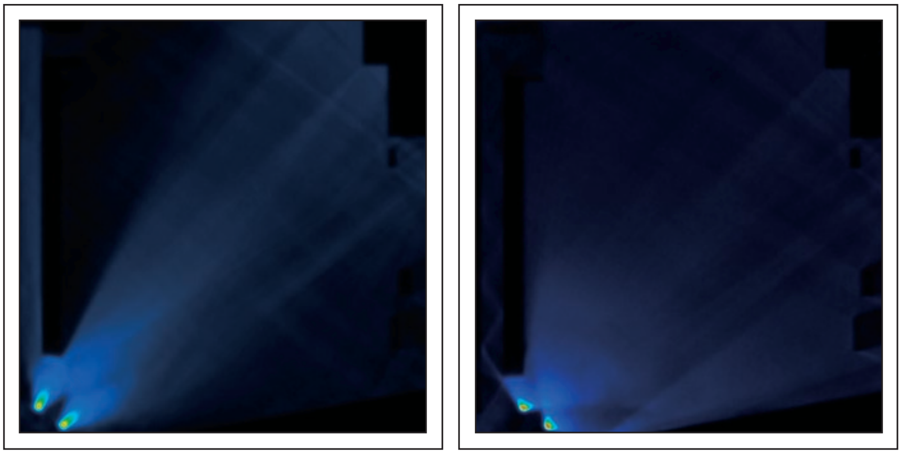
Edge lighting also allows for selective illumination. Figure 3 illustrates how a two-LED light guide measuring 4.3 in. at its widest point, 4.5 in. at its longest point, and only 0.8 mm thick (or less) can backlight a programmable thermostat with multiple discrete areas requiring illumination. These areas include the main 3.5 × 3-in. (4.6-in. diagonal) LCD area, characters, and directional symbols at the top and sides of the unit, as well as the buttons at the top and bottom – nine discrete areas in all. Illumination can range from straight backlighting of the LCD, characters, and symbols to a "halo" effect around the keypad buttons that is aesthetically appealing and functional.

### Optical Modeling with Lens Arrays

A key technique used to enhance uniformity involves lens arrays. Lens arrays are light distribution features that are located on the edge of the light guide (in front of the LED), and they help to provide for a uniform visual appearance using a reduced number of light sources by increasing the angular output distribution of the LED, while minimizing the hot spots that can occur when an LED is too close to the viewing area. The use of lens arrays permits a reduction in the number of LEDs required while still achieving a uniform backlight. This approach enables cost, space, component, and power savings.

In the examples shown in Figs. 4(a) and 4(b), two side-emitting high-brightness LEDs that would best optimize the light coupling to the edge-lit light guide were chosen, then optical modeling using lens arrays was employed to improve the distribution of the light.

A baseline was used to see where the light was going, and LED models were created for the optical ray-trace software. A custom geometry was designed into the tooling of the light guide to better control the spread of the light from the LEDs, and custom optical lens array features were added in front of the LEDs to spread the light more widely than it was in the manufacturer's original design. The lens array (Fig. 5) is positioned at the entrance region on the edge of the light guide.



(a) (b)

***Fig. 4:*** *Two side-emitting high-brightness LEDs that would best optimize the light coupling to the edge-lit light guide were chosen, then optical modeling using lens arrays was used to improve the distribution of the light. A custom geometry was designed into the tooling of the light guide to better control the spread of the light from the LEDs, and custom optical lens array features were added in front of the LEDs to spread the light more widely (b) than it was in the manufacturer's original design (a).*

The shape of these lens arrays can be customized to the application. They are designed to refract the light into a wider output distribution than what would normally be achievable. For example, a typical LED used in edge-lighting applications emits light at a 100–110º distribution angle. Lens arrays can increase this by an additional 10–20º.

### PC Displays

Notebook computers are already switching from CCFL backlights to edge lighting with white phosphor LEDs. For this application, designers typically select a blue LED, which is imbued with an amber phosphor to convert the visible wavelength to white. The white LEDs still deliver a percentage of the color spectrum comparable to CCFL (approximately 75%, compared to 70% for CCFLs) while providing lower power consumption. LED-based backlight modules utilizing advanced RGB LED backlight units, each containing three chips with separate red, green, and blue dice in a single package, offer color saturation above 100% NTSC (~140%), exceeding the 70% NTSC color gamut for conventional CCFL backlight modules and allowing unprecedented high-resolution performance and much thinner solutions than traditional CCFL assemblies.

For desktop monitors in many applications, such as advertising, television production, publishing, and industrial design, RGB LEDs are ideal because they can deliver exceptional color accuracy. In addition to providing truer color, today's high-efficiency edge-lit light guides can disperse the light from a single LED over a much wider area. On the downside, RGB LED choices are limited; they are generally more expensive and because more "transition area" is needed to mix the three colors, the use of RGB LEDs can limit the design flexibility of optical designers.

New, thinner LED-based backlights are being designed into notebook and desktop PC keyboards that provide optimal brightness and uniformity along with the ability to utilize fewer LEDs, reducing the cost of the backlight (Fig. 6).

As with the thermostat example cited previously, a key attribute in keyboard and keypad lighting is to selectively illuminate only those areas where light is required, increasing the

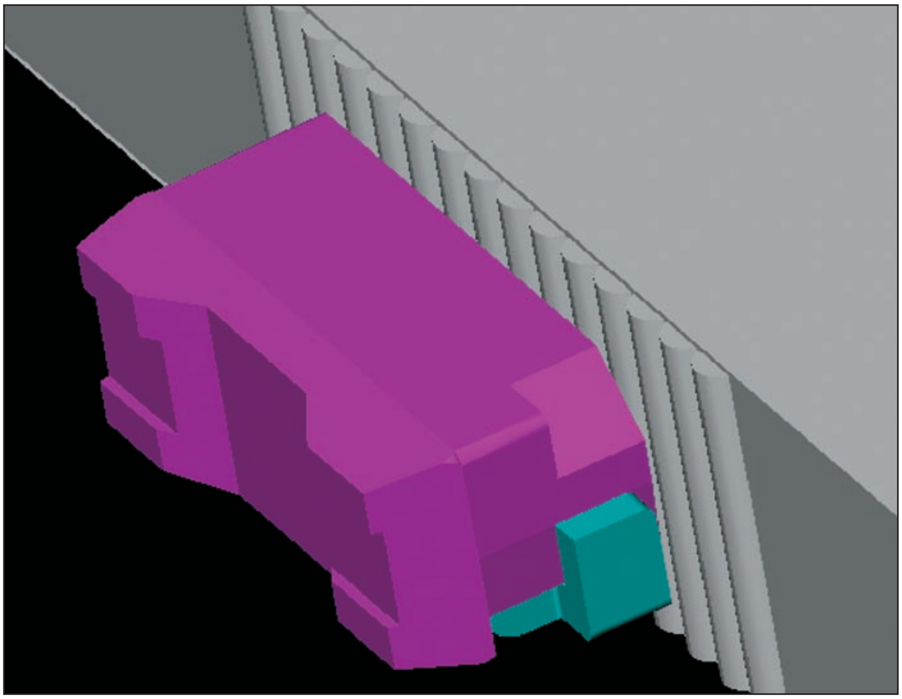


*Fig. 5: Lens arrays located on the edge of the light guide serve to spread light uniformly, while micro-optical elements efficiently extract light at each pixel.*

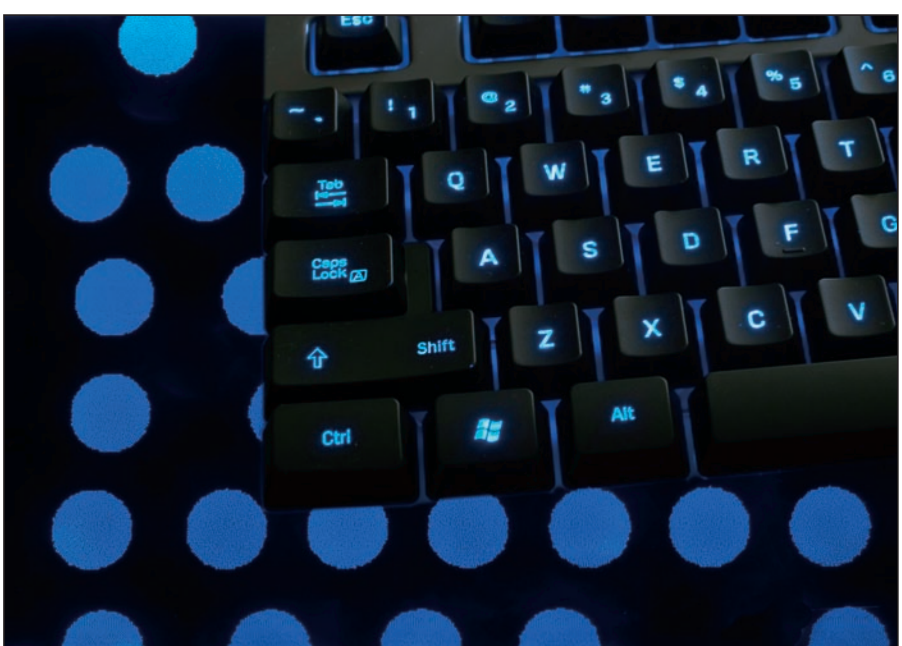


*Fig. 6: New, thinner LED-based backlights are being designed for PC keyboards to provide optimal brightness and uniformity along with the ability to utilize fewer LEDs, reducing the cost of the backlight.*

light output – and brightness – at the precise points, and only at those points, where it is needed.

## LCD TVs

Until recently, edge-lit LED light guides have not had sufficient brightness and efficiency to illuminate large-screen TVs and high-definition displays. One of the newer solutions has been to use the MicroLens light guides in combination with the PhlatLight chipsets to enable the development of an efficient, cost-effective RGB edge-lighting technology with satisfactory brightness and uniformity for large-screen TVs.

Working with Luminus Devices and Jabil Circuit, GLT has developed a 46-in. LCD-TV backlight referred to earlier that consists of eight edge-lit light guides, called "blades." Lens arrays located on the edge of each light guide serve to spread light uniformly, while micro-optical elements efficiently extract light at each pixel.

More recently, a 46-in. "uniblade" backlight has been developed that uses a one-piece ultra-thin light guide only 5 mm thick. This backlight employs 126 RGW LEDs on one side using light-extraction technology, and the total thickness of the backlight assembly is currently only 9 mm. The RGW LEDs are traditional white phosphor LEDs that incorporate an additional red and green phosphor to increase the color gamut to ~ 100% of the NTSC standard. This approach provides extreme brightness of 6000 cd/m$^2$, excellent uniformity of 85%, extreme thinness, and a shorter transition area.

## Conclusion

New advances in light-extraction efficiency, coupled with lens arrays and optical modeling techniques, are utilizing the increased brightness of today's high-brightness LEDs to create large-sized edge-lit light-guide BLUs that are growing steadily thinner, requiring the use of fewer LEDs. In this way, manufacturers can meet the increasing demands of today's consumers for ever thinner, brighter, and more feature-packed devices. ■



# Issues in High-Volume Manufacturing of Large-Screen LED-Backlit LCDs

*Environmental concerns, including initiatives for the reduction of hazardous materials and requirements for reduced energy consumption and longer product life, are driving the need for non-CCFL-based backlight technologies. Cost and technology barriers have historically kept the volumes of LED-based solutions low, although that situation is now changing.*

by Evan O'Sullivan and Bob Pantalone

LIGHT-EMITTING DIODES (LEDs) have been used for many years as the backlight for laptops and small desktop flat-screen displays. LEDs allow these displays to be thinner and to dissipate less power than other backlight alternatives. The natural progression for this technology would be an expansion into larger screen sizes, but the adoption has been slow. Early large-screen implementations used a direct-lit array of hundreds to thousands of LEDs to replace the lamps on a standard backlight. More recently, a few large-screen displays have adopted the same method of edge lighting that was previously implemented in smaller displays (Fig. 1). LED-based systems have conventionally faced cost and yield issues, but recent breakthroughs in LED efficiency and lower-cost packaging are making the adoption more possible than ever before. These technical advancements, coupled with the high priority on the part of OEMs of making products more eco-friendly, are paving the way for LED backlights to garner a much larger market share in the next 2–3 years.

Regardless of the implementation (direct-lit or edge-lit) used, there are important factors to be considered when moving from prototype quantities to high-volume manufacturing.

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***Fig. 1:** One of the first edge-lit LED-backlit LCD TVs was this 32-in. version shown at the 2005 SID International Symposium in Boston. Today, this sized LCD can be backlit by as few as six RGB LEDs.*



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This article examines the most important of these challenges and offers some advice on how to address the issues.

## LED Issues

It is well understood within the LED industry that a variation of LED color-point and lumen output will be expected during the high-volume manufacture of LEDs. This variation is the driver for binning in the LED industry. In some applications, a variation in lumen output and color point may have little effect on the end-customer's viewing experience; however, display backlighting is not a very tolerant application for LED variations because these variations will affect both brightness and color uniformity. Typical brightness-uniformity specifications are greater than 85%, and color-uniformity specifications are ±0.03 from the desired color-point X,Y setting.

There are many efforts under way by LED manufacturers to achieve tighter and more predictable control over the variation in LEDs. One such effort is Philips's Lumiramic phosphor technology, which is designed to enable tighter control of correlated color temperature (CCT) and to reduce the number of bins for a given CCT by 75% or more for white LEDs. Until the LED industry can tightly control LED variations, a high-volume product must either be able to tolerate these variations or else be able to rely on a very specific bin of LEDs and accept the associated extra cost and possible lack of supply associated with this approach.

A robust LED driver design should account for lumen-output differences in LEDs, whether the backlight consists of white or RGB LEDs. The current through each LED can be controlled in implementations using a small number of high-power LEDs, or the current through a string of LEDs can be adjusted for implementations using a large number of low-power LEDs. These adjustments must be made during the manufacturing process to calibrate the brightness uniformity of the backlight unit (BLU).

For white-LED implementations, there is little that can be done to account for variations in color (white) point, so care must be taken to use pre-determined matched bins of LEDs. For RGB implementations, the duty cycle that each color is driven by can be adjusted to make corrections to obtain the desired color point, sometimes at the cost of brightness.

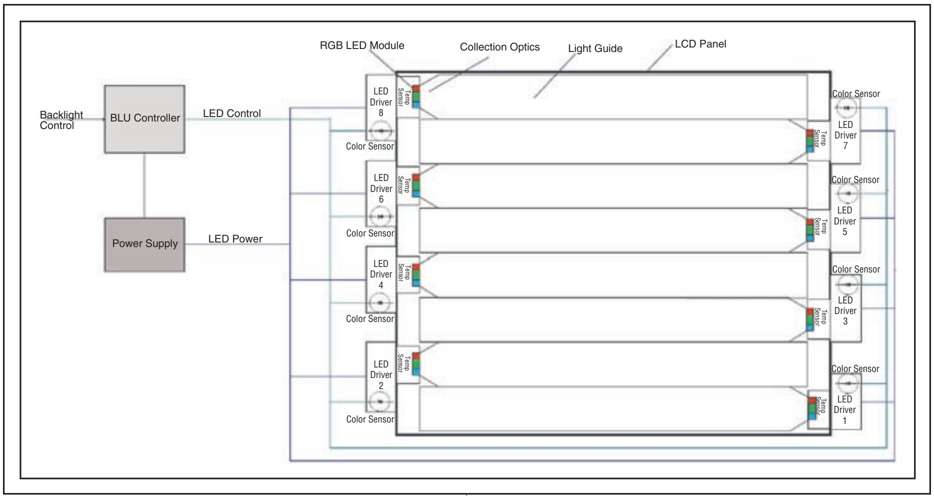


***Fig. 2:** Ilustrated is an edge-lit LED-backlight LCD-TV block diagram showing the bladed approach incorporating horizontal sections of the light guide with attached LEDs.*

A secondary issue with LEDs is their degradation over time. Without the benefit of having LED backlights in the marketplace for a number of years, it is up to the individual designer to determine if the variation in the degradation of LEDs over time will be acceptable or if some type of aging correction should be performed at predetermined usage periods. Without aging correction, the white/color point will shift. In a backlight system that incorporates multiple LEDs, these LEDs will degrade at slightly different rates over time. This results in the need to tune the operation of individual LEDs, or perhaps small groups of LEDs, in order to maintain a uniform brightness and color point over time for an entire backlight. This aging correction can be performed in a manner similar to the initial calibration and one or more light/color sensors must be added to the system to provide a feedback loop for recalibrating the color/white point and lumen output of the LEDs.

The following discusses an edge-lit RGB-LED-backlight LCD-TV design and shows how it handles LED aging.

Figure 2 shows an example of an edge-lit LED-backlit LCD TV that incorporates a bladed-light-guide approach (using horizontal sections of a light guide with attached LEDs) with RGB LEDs and color sensors used for aging correction. The system uses a microprocessor-based adaptive control system to progressively control each blade and also maintains a consistent color-point performance. Color sensors installed behind each blade measure the color saturation and tristimulus value for a given LED color. This value is used adaptively by the microprocessor to correct the non-linearities that arise due to LED aging and thermal changes.

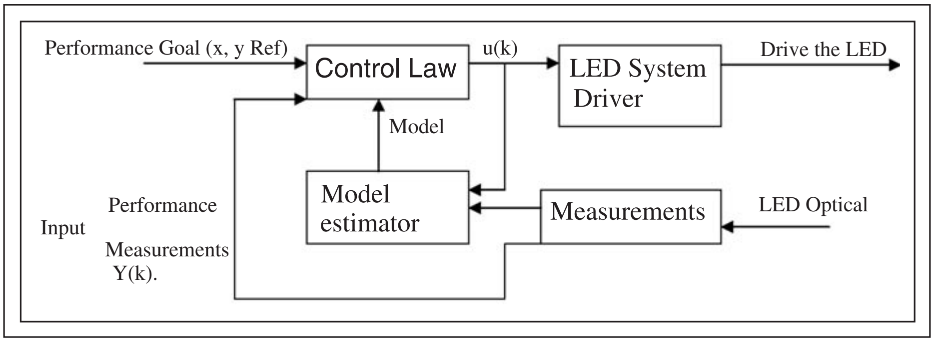


***Fig. 3:** Schematic of the "Self Tuning Regualtor" mechanism of the adaptive algorithm.*

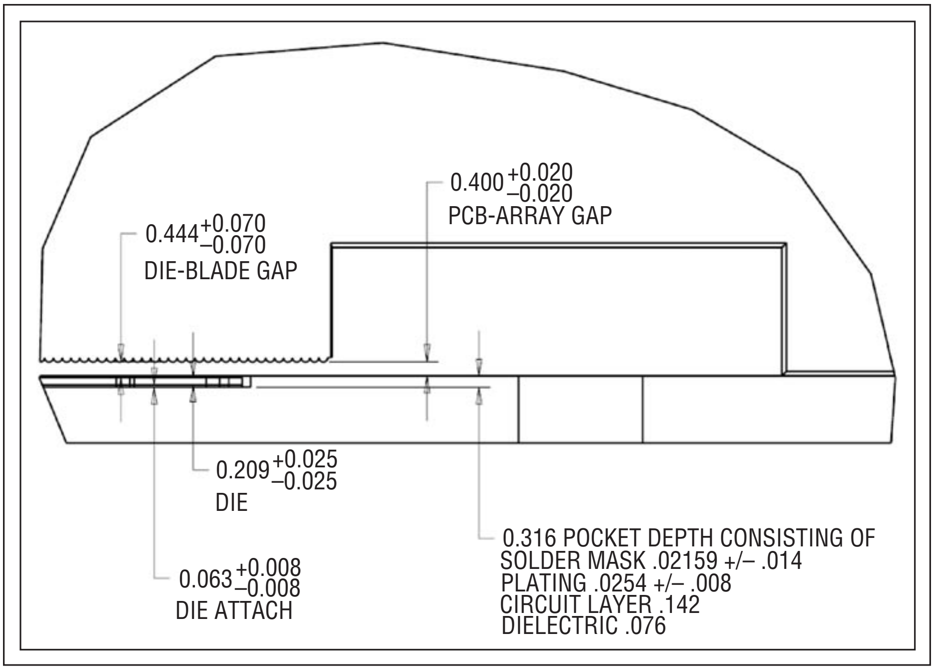


*Fig. 4: Cross-sectional view of the LED die and light guide (blade).*

The adaptive algorithm used is a "Self-Tuning-Regulator" mechanism and is depicted in Fig. 3. The control law and model estimator modules are the two critical components of the mechanism, and these modules are invoked at a periodic sampling time. The best-suited model estimator for the given scenario is an *n*th-order polynomial regression. The reference polynomial regression is constructed one time, based on the LED's subsystem behavioral response. Any performance changes over time are dynamically compensated through new model estimates. Based on these new inputs, the control law drives the system to achieve the performance goal.

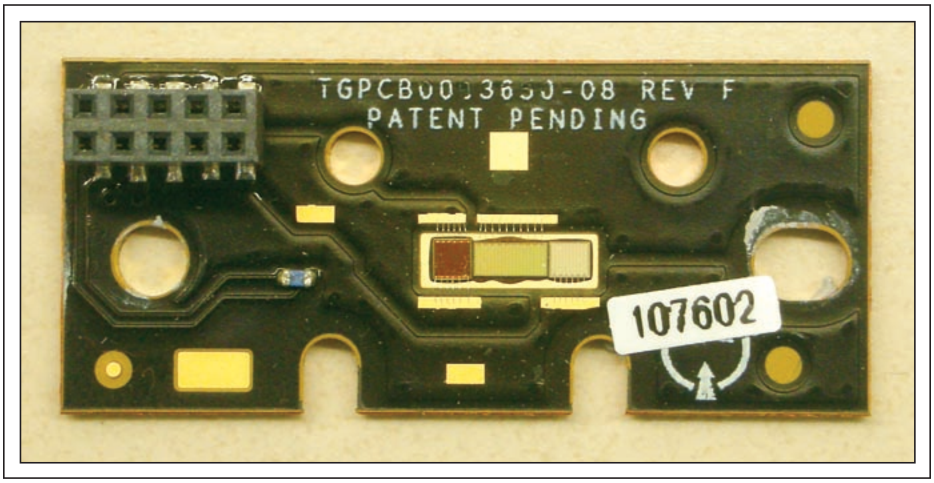


*Fig. 5: This photo shows LED dice placed directly onto a printed-circuit board and wire-bonded directly to the circuit board with no protective package or window. Packaging choices such as these improve the system performance, but also create the need for new handling and manufacturing processes.*

*u*(*k*) is the activator variable derived from the performance goal, estimated model, and performance measurements. The model estimator estimates the system behavior for a given input and predicts the model. This model estimation is based on a one-time system learning process:

With time, this behavior will change due to several conditions explained above; thus, model prediction, combined with performance goal, and current performance measurement is key in order to achieve the goal.

### Aging Control

As LEDs age, their brightness performance begins to degrade. A study of this decay can help the adaptive algorithm to correct for this effect periodically. The adaptive algorithm monitors the LEDs' performance by using a built-in color sensor in order to obtain a precise state of decay and then applies compensation to offset this change. The decay factor is propagated to the dynamic-brightness-control algorithm to adapt this new decay change factor. This will allow accurate white-point preservation over time.

### Manufacturing Issues

The electrical to optical efficiency of an LED-based backlight is dependent on a number of parameters. Certainly, the efficiency of the driver scheme is important, but once the driver design is set, the variation from system to system must be minimal. Light leakage and light coupling are two other areas that can drastically affect the efficiency of the system. For edge-lit systems, the light guide is the primary optical component, and its design determines much of this loss. Losses can range from 5% to 10% in well-designed systems, to 15% and more in poorly designed systems. Once the light-guide mold is created, the variations from system to system will be minimal.

The mechanical positioning of the LEDs with respect to the light guide is crucial for capturing the maximum amount of light output from the LEDs. Care must be taken to ensure that the LED is properly aligned to the light collecting surface of the light guide, which in this case requires that the LED is at a 90° angle from the light guide, and that any air gap between the LED die and the light guide is tightly controlled. Control of the air-gap distance is crucial, due to the dispersion angle of the light emitted from the LED,

*Fig. 6: Having proper rework procedures in place to repair failed systems is important. Here, a rework technician using approved handling and rework processes repairs a failed LED PCB from a backlight module.*

which in most cases is a lambertion pattern. While achieving a direct connection with no air gap would be ideal, it is not currently practical because of the height required for the wire bonds on the LED die. Hence, a very small air gap is required.

A robust design will achieve these close tolerances without over-complicating the manufacturing process. Figure 4 shows a typical implementation and the tight tolerances needed to ensure a robust design.

Large light guides can be manufactured in small quantities using various techniques, but these techniques do not necessarily translate into a high-volume solution. Light-extraction features can be molded into the light guide, printed onto the light guide, or cut/scored onto the surface. Each method – molding, printing, or cut-scoring – has its own merits and drawbacks, but the ability to consistently create the same light-extraction patterns will affect the uniformity of the system.

LED packaging for backlight applications may not meet the robust standards of the LEDs that most manufacturers are familiar with handling. In some cases, the optics or protective glass windows may be removed to improve coupling and LEDs may be wire-bonded directly to a printed-circuit board to maximize heat transfer (Fig. 5). The opportunity for damaging these components can become a real problem in a high-volume environment if proper care is not taken in the handling and placement of these devices.

High-volume manufacturing of LED-backlight systems also requires more attention to rework procedures for repairing failed systems (Fig. 6). Not only is handling an issue during the rework process, but care must be taken to use methods that do not over-stress the LEDs or the LED packaging. Developing a close relationship with the LED supplier will help ensure that the processes used will not cause catastrophic or latent LED issues.

A final word of caution relates to the selection of other system components, most notably the system power supply. The LEDs in an LED-based backlight may have a stated reliability of 50,000 hours or greater, but the system reliability number may be no better than current products if the other components in the system are not carefully selected for high reliability. Also, LED reliability is extremely dependent on the operating temperature of the LED die, so care must be taken when choosing components used for dissipating heat. The junction temperature of the LED has a large effect on its wavelength, brightness, and life. Typically, a junction temperature over 65°C will cause some degradation in these parameters.

The use of LEDs as a light source for backlighting is not new, but their use in high-volume large-screen-sized applications is still in its infancy. What is needed is a robust design that will meet the required brightness and color specifications without the need to specify a very narrow bin of LEDs. Manufacturers of high-volume products that are not familiar with using LEDs for backlight applications will need to educate themselves on the proper handling and repair of these systems. The realization of high-volume LED backlights for large-screen displays is a certainty in the near future and with care and attention to the product design and the assembly process, these products will certainly deliver on their promise of low power, high reliability, and enhanced user experience. ■

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# San Antonio to Host Display Week 2009

*Display Week gets done Texas-style this year in San Antonio, Texas, with one of the oldest cities in the American West hosting some of the latest display technology in the world. Here's what to see and do when you're not attending Display Week 2009.*

## by Jenny Donelan

"REMEMBER THE ALAMO!" and "Don't forget the River Walk!" are standard marching orders for most visitors to San Antonio. And while these attractions are consistently and deservedly ranked among the top 10 in all of Texas, there are many other things to see and do in this sunny city with Spanish roots. Visitors to Display Week 2009 (The SID International Symposium, Seminar & Exhibition) can also enjoy historic sites, open-air markets and dining, world-class museums, and, of course, the region's legendary Tejano culture.

Whatever you do in San Antonio, do some of it outdoors. Temperatures average between 72 and 92°F in June. Bright days are the norm, with the city enjoying an average of 300 days of sunshine. So, take a walk.

### The Big Two

The ***Alamo*** and the ***River Walk*** are an easy stroll from the Henry B. Gonzalez Convention Center, where Display Week will take place. They are not to be missed. If you only have time to see two things besides the show floor and the inside of your hotel room while at the conference, by all means get yourself to the River Walk and the Alamo.

So why are we supposed to remember the Alamo, anyway? It's where, during the Texas Revolution in 1836, 189 Texas defenders held off Mexican General Santa Anna's 4000 soldiers for 13 days. After those 13 hard-fought days, things went distinctly worse for the defenders, so we honor their lost lives through memory. The 300-year-old Alamo, originally a mission, is often referred to as "the shrine of Texas liberty," and looms large in the patriotic mental landscapes of U.S. citizens and of Texans especially.

First-time visitors to the ***Alamo*** may be in for a surprise if they have imagined it as (a) large or (b) in a barren landscape as it appears in films such as the 1960 John Wayne movie by the same name. The Alamo is actually not one building, but a 4.2-acre complex including three modest buildings and a garden. And it is directly in the middle of the city. Still, the sense of history in this place is palpable. For example, as a sign of respect, gentlemen are still instructed to remove their hats when

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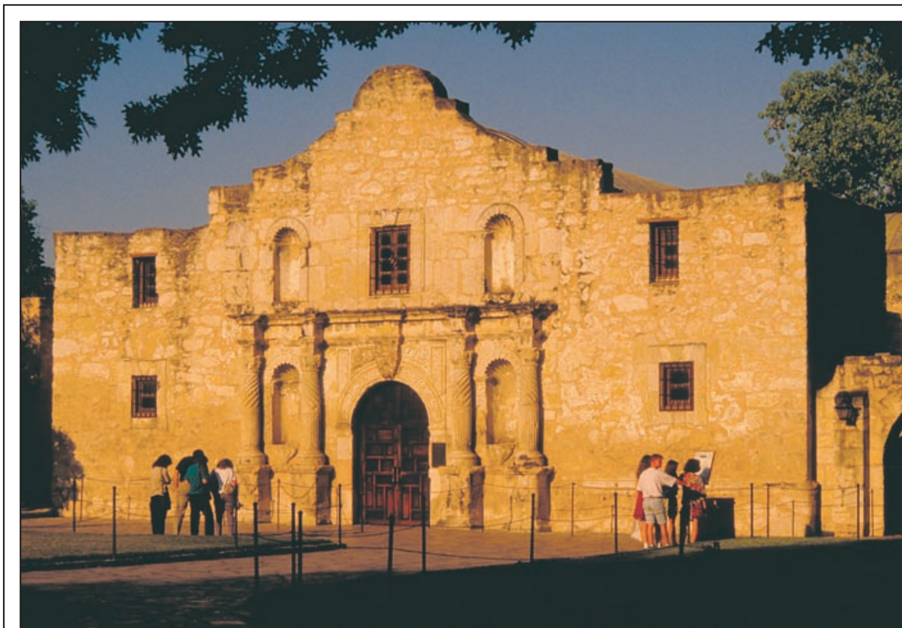

*The landmark known as the Alamo was originally the Mission San Antonio de Valero, founded by the Spanish in 1718. Photo Courtesy of the San Antonio Convention & Visitors Bureau/ Al Rendon.*



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entering the complex. You can take a look at the grounds most any time of day and visit the indoor exhibits during open hours. The Alamo is operated by the Daughters of the Republic of Texas.

The ***River Walk*** (also known as the Paseo del Río) is just a short distance from the Alamo. It consists of a network of pedestrian walkways, lined with restaurants and shops, that runs along the San Antonio River below street level. Perhaps that depth is what gives the River Walk a sense of being its own world, a city within a city. In any case, it's a great place to relax. Set yourself up with a prickly pear margarita at a café along the water, order guacamole to be made at your table, and watch the parade of colorful, tourist-filled boats pass by. You can take a river taxi or tour yourself, or even dine on a boat. Many of the local restaurants offer on-river dining.

## A Sense of History

San Antonio was the site of a native American settlement when a Franciscan Father stopped by and bestowed its current name on it sometime in the late 17th century. In 1718, Spain established the Mission San Antonio de Valero (later to be called the Alamo) on the site. Consequently, San Antonio is an old city by Western standards, and one with a unique mixture of native American, Mexican, Spanish, German, and other European settlers.

***The San Antonio Missions National Historic Park*** contains a grist mill and four historic missions: Concepción, San José, San Juan, and Espada. Each mission is still an active Catholic parish that holds regular services. If you have time, you can travel from mission to mission on the 8-mile Missions Bike and Hike Trail.

Built by German merchants in the late 1800s, the ***King William Historic District*** is the oldest historic district in Texas. You can take a self-guided walking tour (available

*River boat tours and riverside dining are both popular with visitors to San Antonio. Photo courtesy of the San Antonio Convention & Visitors Bureau/Al Rendon.*

## Getting to and around San Antonio

San Antonio International Airport (SAT) is located about 8 miles from the center of town. A taxi ride from the airport to the city center takes about 20 minutes and costs approximately $25. SATRANS, the San Antonio Airport Shuttle, also offers transportation to all the downtown hotels for about $18. You can book a shuttle in advance online or buy a ticket in the baggage claim area once you arrive.

For more information contact:

- ***Airport:*** http://www.sanantonio.gov/aviation
- ***SATRANS:*** http://www.saairportshuttle.com

A great place to start your visit is the San Antonio Visitor Center (http://www.visitsanantonio.com/visitors/plan/visitor-information-center/index.aspx), located across from the Alamo. Many of the major sites in San Antonio are within walking distance of the convention center, but the city also offers several public-transportation options designed especially for visitors:

- ***Streetcar:*** These are open-air reproductions of the type of rail streetcar that serviced San Antonio more than half a century ago. Four streetcar routes stop at sights such as the Alamo and La Villita, and in downtown shopping areas. There is a streetcar station near the convention center. A one-day pass is $4.
- ***River Taxi:*** River cruisers with black and yellow checkered flags stop at 39 locations along the River Walk. A one-way pass is $4; a 24-hour pass is $10.
- ***Sightseer Special Bus:*** Bus 7 runs daily between the city's popular sites, including the River Walk Streetcar Station, Henry B. Gonzalez Convention Center, the Alamo, the San Antonio Museum of Art, and the San Antonio Zoo.

For more information on bus and streetcar service in San Antonio contact:

- ***Via Metropolitan Transit:*** http://www.viainfo.net

For river tours, river taxis, and on-board dining contact:

- ***Rio San Antonio Cruises:*** http://www.riosanantonio.com

## Web Sites for San Antonio

**General Information**

- ***The Official Site of Texas Tourism***: www.traveltex.com
- ***San Antonio Convention & Visitors Bureau***: http://www.visitsanantonio.com/visitors/plan/visitor-information-center

**Historic Attractions**

- ***The Alamo:*** www.thealamo.org
- ***King William Historic District:*** http://www.saconservation.org/tours/sitevisits_kingwilliam.htm
- ***La Villita Historic Arts Village:*** http://www.lavillita.com
- ***San Antonio Missions National Historic Park:*** http://www.nps.gov/saan

**Destinations**

- ***The River Walk:*** http://www.thesanantonioriverwalk.com
- ***San Antonio Zoo and Aquarium:*** http://www.sazoo-aq.org
- ***Tower of the Americas:*** http://www.toweroftheamericas.com

**Museums**

- ***Buckhorn Saloon & Museum:*** http://www.buckhornmuseum.com
- ***McNay Art Museum:*** http://www.mcnayart.org
- ***San Antonio Museum of Art:*** http://www.samuseum.org/main

**Theme Parks**

- ***Schlitterbahn Waterpark Resort:*** http://www.schlitterbahn.com/nb
- ***SeaWorld San Antonio:*** http://www.seaworld.com/sanantonio
- ***Six Flags Fiesta Texas:*** http://www.sixflags.com/fiestaTexas

from the San Antonio Conservation Society as listed later in this article) to view the neighborhood's large, impressive houses. There are also restaurants, bed-and-breakfasts, and art galleries.

***La Villita Historical Art Village***, "the little village," is located on the south bank of the San Antonio River. La Villita was San Antonio's first neighborhood, established by Spanish soldiers stationed at the Alamo. Now it's home to art galleries, craft and jewelry shops, clothing stores, and numerous restaurants.

### A View and a Zoo

History of a different sort is evident at the ***Tower of the Americas***, an observation tower that looks exactly like the 1968 World's Fair centerpiece it once was. The observation deck and revolving restaurant have recently undergone renovations, however. You can ride a glass elevator up the structure to literally upscale dining, enjoying unbeatable views all the way. The Tower also features a 4-D ride called "Skies Over Texas."

The ***San Antonio Zoo and Aquarium*** is the third largest in Texas and one of the oldest zoos in the country as well. More than 3500 animals representing 600 species are on hand here. At press time, the aquarium was being renovated and was scheduled to reopen in the spring.

### High and Low Culture

San Antonio has many more museums than can be listed here. One of the most famous is the ***McNay Art Museum***, known for its collection of 19th- and 20th-century European and American art displayed in a Mediterranean villa and courtyard. The McNay Art Museum was the first museum of modern art in Texas. Among the painters and sculptors represented here are Paul Cézanne, Vincent van Gogh, Auguste Rodin, Henri Matisse, Pablo Picasso, Edward Hopper, and Georgia O'Keeffe.

You'll also want to be sure to check out the ***San Antonio Museum of Art***, housed in a turn-of-the-century building that was once the Lone Star Brewery. This museum has the most comprehensive collection of Latin American art in the United States, as well as an assembly of Egyptian, Roman, and Greek antiquities.

Because you really are in the southwest after all, a must-see is the ***Buckhorn Saloon***


*Tex-Mex dining is an important part of any visit to San Antonio. Photo courtesy of the San Antonio Convention & Visitors Bureau/Stephanie Colgan.*

***& Museum***, which includes separate museums dedicated to horns, fins, and feathers (yup), as well as the Hall of Texas History Wax Museum (which also, not incidentally, had its start at the 1968 World's Fair). There is a curio store dating back to 1920 and last, but not least, an actual saloon in which you can enjoy a cold frosty rootbeer or other beverages of your choice at the venerable establishment's 120-year-old bar.

### Theme Parks Wet, Wetter, and Wettest

***Six Flags Fiesta Texas*** boasts eight roller coasters, including the famed Superman Krypton Coaster, the largest steel coaster in the southwest, and Big Bender, with its tunnels, waterfalls, and five-story drop. There's also a 90-ft. Ferris wheel, a boardwalk, shows, and much more.

***SeaWorld San Antonio*** is the largest marine-life adventure park in the world. You can ogle the sea life at a show at Shamu Stadium, then visit any of SeaWorld's four individual parks, including some with water rides.

Water park connoisseurs speak in reverent tones of ***Schlitterbahn Waterpark Resort*** in New Braunfels, Texas, about 40 minutes north of San Antonio. The state-of-the-art resort has 65 acres of water-based amusements, including an uphill water coaster six stories tall, miles of tube chutes, kid-friendly water playgrounds, and river rafting.

Even though San Antonio is the second-largest city in Texas, it's not so large that you can't see at least some of it when you're not taking in seminars, presentations, and exhibits at Display Week. Set aside a little time to soak up some southwest Texas sun and a lot of local Latin flavor. And whatever you do, don't forget the ... you know what. ■

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# Journal of the SOCIETY FOR INFORMATION DISPLAY

**A preview of some of the most interesting papers appearing in the February 2009 issue of the *Journal of the SID.* To obtain access to these articles on-line, please go to www.sid.org**

Edited by Aris Silzars

## An 82-in. ultra-definition 120-Hz LCD TV using new driving scheme and advanced Super PVA technology

**Sang Soo Kim** (SID Member)
**Bong Hyun You** (SID Member)
**Jung Hwan Cho**
**Dong Gyu Kim**
**Brian H. Berkeley** (SID Senior Member)
**Nam Deog Kim** (SID Member)

*Samsung Electronics Co., Ltd.*

***Abstract*** — An ultra-definition (UD or 3840 × 2160) resolution 82-in. product with 120-Hz high-frame-rate driving has been developed for LCD-TV applications. The resolution increase from full HD to UD greatly reduces the available charging time. This problem has been overcome by employing a half-gate two-data-line design (hG-2D) for Super PVA pixels. Additionally, cost-effective single-bank driving has been achieved by adopting a vertical-quarter-partitioned (VQP) driving scheme. A viewing angle of 180°, contrast ratio of 2200:1, and brightness of 550 nits have been achieved while maintaining all of the other advantages of the Super-PVA structure.

The hG-2D pixel's operation is shown in Fig. 11. Sub-pixel B almost stays black at a data input below 25% of full white, but grows brighter with increasing gray values. For the best viewing-angle performance, these two subpixels are optimized at an area ratio of 2:1. Looking at Fig. 11(c), which shows the CS S-PVA pixel displaying a full white pattern, it is not easy to identify a brightness difference between sub-pixels A and B. However, the brightness of sub-pixel B is measured to be 30% lower than that of subpixel A. This is due to the loss of charge when TFT3 is switched on.

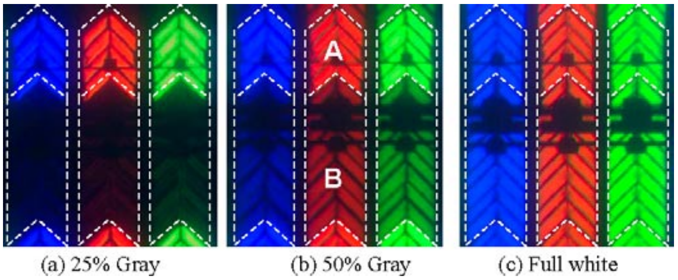


**FIGURE 11** — Pixel operation of CS super-PVA. (a) 25% gray, (b) 50% gray, and (c) full white.

## Active-matrix sensor in AMLCD detecting liquid-crystal capacitance with LTPS-TFT technology

**Eiji Kanda** (SID Member)
**Tsukasa Eguchi, Yasunori Hiyoshi**
**Taketo Chino, Yasushi Tsuchiya**
**Takahiro Iwashita**
**Tokuro Ozawa** (SID Member)
**Takao Miyazawa**
**Tomotaka Matsumoto** (SID Member)

*Seiko-Epson Corp.*

***Abstract*** — An active-matrix capacitive sensor for use in AMLCDs as an in-cell touch screen has been developed. Pixel sensor circuits are embedded in each pixel by using low-temperature polycrystalline-silicon (LTPS) TFT technology. It detects a change in the liquid-crystal capacitance when it is touched. It is thin, light weight, highly sensitive, and detects three or more touch events simultaneously.

Figure 2 shows a partial cross section of the LCD panel. The manufacturing process was designed to be the same process as that for a standard LCD because the sensing components consist of the same components as a standard LCD array. The fabrication does not require additional process steps and does not cause an increase in cost. Furthermore, a fringe-field switching (FFS) mode structure was used because the sensing circuit capacitance is easy to optimize. In the FFS structure, the common electrode is on the TFT substrate.

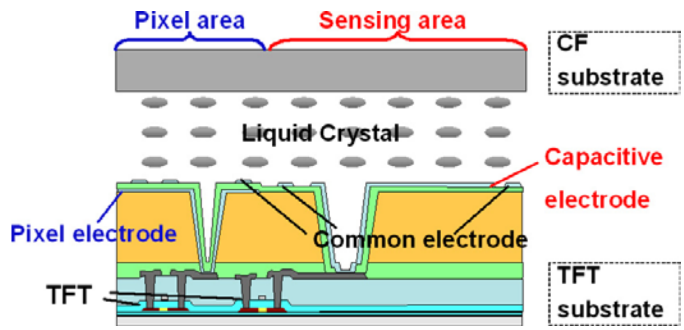


**FIGURE 2** — Cross section of the manufactured LCD. The manufacturing process was designed to be the same process as for a standard LCD. The thickness of both substrates is 0.5 mm.

## 12.1-in. WXGA AMOLED display driven by InGaZnO thin-film transistors

**Jae Kyeong Jeong** (SID Member)
**Jong Han Jeong**
**Hui Won Yang**
**Tae Kyung Ahn**
**Minkyu Kim**
**Kwang Suk Kim**
**Bon Seog Gu**
**Hyun-Joong Chung**
**Jin–Seong Park**
**Yeon-Gon Mo**
**Hye Dong Kim**
**Ho Kyoon Chung**

*Samsung SDI Co., Ltd.*

***Abstract*** — A full-color 12.1-in. WXGA active-matrix organic-light-emitting-diode (AMOLED) display was, for the first time, demonstrated using indium-gallium-zinc oxide (IGZO) thin-film transistors (TFTs) as an active-matrix backplane. It was found that the fabricated AMOLED display did not suffer from the well-known pixel non-uniformity in luminance, even though the simple structure consisting of two transistors and one capacitor was adopted as the unit pixel circuit, which was attributed to the amorphous nature of IGZO semiconductors. The *n*-channel a-IGZO TFTs exhibited a field-effect mobility of 17 $cm^2$/V-sec, threshold voltage of 1.1 V, on/off ratio > $10^9$, and subthreshold gate swing of 0.28 V/dec. The AMOLED display with a-IGZO TFT array is promising for large-sized applications such as notebook PCs and HDTVs because the a-IGZO semiconductor can be deposited on large glass substrates (larger than Gen 7) using the conventional sputtering system.

Figure 1 shows a schematic cross section of the IGZO TFTs, which have an inverted-staggered bottom-gate architecture with an ESL. For an a-IGZO TFT without an ESL, severe degradation of the subthreshold gate swing and the uniformity of threshold voltage were observed. This is why an ESL-type structure rather than a back-channel etch structure was chosen, which is generally adopted for LCDs.

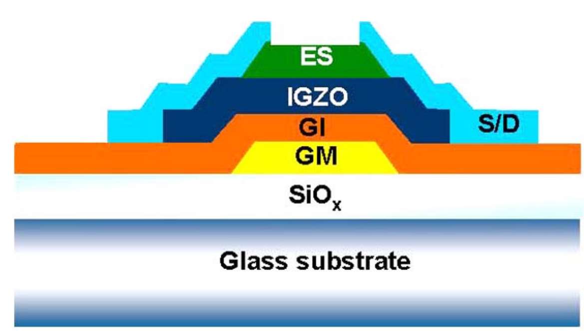


**FIGURE 1** — The schematic cross section of an a-IGZO TFT with an inverted-staggered architecture.

# Touch-screen panel integrated into 12.1-in. a-Si:H TFT-LCD

**Bong Hyun You** (SID Member)
**Byoung Jun Lee**
**Sang Youn Han**
**Seiki Takahashi**
**Brian H. Berkeley** (SID Senior Member)
**Nam Deog Kim** (SID Member)
**Sang Soo Kim** (SID Member)

*Samsung Electronics Co., Ltd.*

***Abstract*** — A touch-screen-panel (TSP) embedded 12.1-in. LCD employing a standard existing a-Si:H TFT-LCD process has been successfully developed. Compared with conventional external touch-screen panels, which use additional components to detect touch events, the new internal TSP exhibits a clearer image and improved touch feeling, as well as increased sensing speed using discrete sensing lines to enable higher-speed sensing functions including handwriting. The new internal digital switching TSP can be fabricated with low cost because it does not require any additional process steps compared to a standard a-Si:H TFT-LCD.

Figure 4 illustrates the schematic cross-sectional view of the basic structure of the new internal TSP. In this structure, the conductive CS formed on the color-filter glass acts as a sensor switch which connects the common electrode voltage ($V_{COM}$) of the upper color-filter glass to the ITO sensor block on the lower TFT glass. When a touch event occurs, the gap between the conductive CS and contact area (sensor block) is reduced by way of mechanical force so as to make mechanical contact. The conductive CS contact areas are located in each blue pixel.

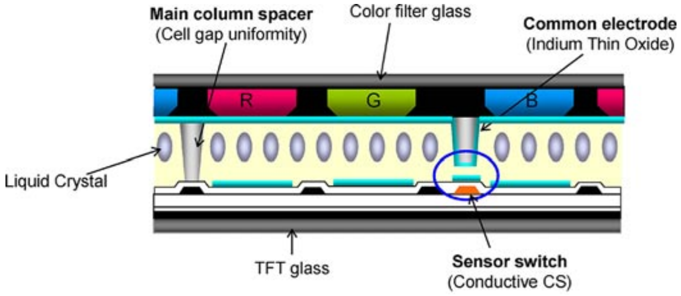


**FIGURE 4** — Schematic view of internal TSP structure. (a) Cross-sectional side view. (b) Top view.

# Dual-plate OLED display (DOD) based on amorphous-silicon (a-Si) TFT backplane

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**In Byeong Kang**
**Byung-Chul Ahn** (SID Member)
**In Jae Chung** (SID Member)

*LG Display*

***Abstract*** — An improved AMOLED with an a-Si TFT backplane based on a unique structure is reported. The new structure is refered to as a dual-plate OLED display (DOD). While a top-emission OLED array is directly fabricated on a TFT backplane, the DOD consists of an upper OLED substrate and a lower TFT substrate, which are independently fabricated. Because the OLED substrate, which is fabricated through the process flow of bottom emission, is attached to the TFT substrate, the light is emitted in the opposite direction to the TFT backplane. The DOD enables the design of large-sized TFTs and a complicated pixel circuit. It can also not only achieve higher uniformity in luminance in large-sized displays due to the low electrical resistance of the common electrode, but also wider viewing angles.

The DOD structure consists of two plates where TFTs are on the bottom plate and OLEDs are on the top plate, connected by a contact spacer as illustrated in Fig. 1. Both plates are separately made and encapsulated afterwards. This method provides a yield higher than that for the conventional method by separately screening bad plates method.

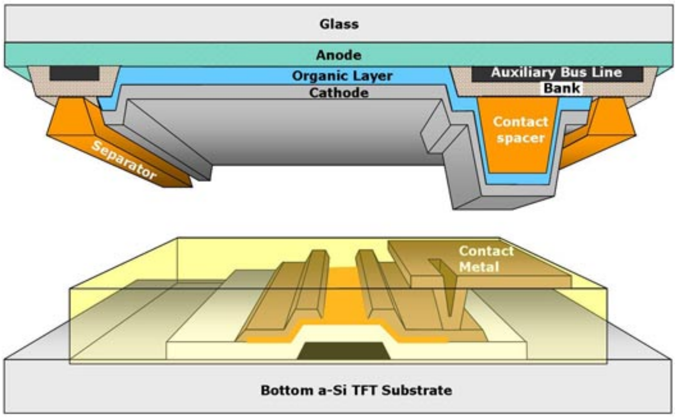



**FIGURE 1** — Cross section of DOD (dual-plate OLED display) after encapsulation. The DOD structure consists of two plates which consist of the TFT on the bottom plate and the OLED on top plate, connected by a contact spacer.

## High-contrast driving method for advanced CEL structure with magnesium oxide single-crystal powder in ACPDP

**Koji Hashimoto** (SID Member)
**Shunsuke Itakura**
**Kazuaki Sakata**
**Tsutomu Tokunaga**
**Mitsuhiro Ishizuka**
**Shigeru Iwaoka**
**Nobuhiko Saegusa**

*Pioneer Corp.*

***Abstract*** — A new driving method for an advanced-CEL-structure panel has been developed. Picture qualities have been upgraded. Discharge time lags are drastically shortened by priming electron emission from magnesium oxide (MgO) single-crystal powder, refered to as a crystal emissive layer (CEL). The advanced-CEL-structure panel has CEL material on the surface of not only the surface-discharge-electrode side but also on the address-electrode side. This panel structure enables a stable opposed discharge when the address electrode functions as a cathode. By utilizing the opposed discharges in the reset and LSB-SF sustain periods, the dark-room contrast ratio has been drastically increased to over 20,000:1, which is higher than five times that of the conventional method, and the luminance of the least-significant-bit sub-field (LSB-SF) is as low as 0.1 cd/$m^2$, which is one-fourth that of the conventional method. The high-picture-quality PDP TVs refered to as "KURO" that employs these technologies have been introduced into the marketplace.

The CEL is a single-crystal powder of MgO, which can emit exo-electrons effectively. And the amount of priming particles in the discharge cells with CEL attenuates more slowly than that without CEL, when the voltage pulse is not applied after discharge. Figure 7 shows the advanced CEL structure. CEL material is formed not only on the front-plate side but also on the rear-plate side. Thus, the discharge, in which A-electrodes can work as cathodes, can be stably generated.

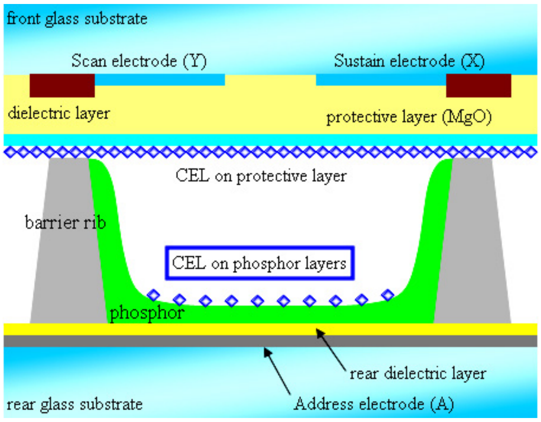



**FIGURE 7** — Advanced CEL cell structure.

## Improved discharge characteristics using MgO single-crystal particles and advanced CEL structure

**Taro Naoi** (SID Member)
**Hai Lin**
**Atsushi Hirota**
**Eishiro Otani**
**Kimio Amemiya** (SID Member)

*Pioneer Corp.*

***Abstract*** — Pioneer Corporation introduced plasma-display-panel (PDP) TVs in 2005, which achieved the highest dark-room contrast ratio of 4000:1 at the time. These PDPs had a novel discharge cell structure consisting of a crystal emissive layer (CEL) on a MgO protective thin film. This cell structure is refered to as a CEL structure. Magnesium-oxide single-crystal particles, which have a unique luminance peak around 230–250 nm and a good exo-electron-emission property, were found to be an excellent material for CEL and were utilized in CEL panels. In 2007, newly developed PDP TVs in which CEL was formed on a phosphor layer, in addition to the previous CEL structure, were introduced, and this discharge cell structure is refered to as advanced CEL structure. By using the new cell structure, the opposed discharge characteristics have been drastically improved, and a stable reset discharge has been realized with only a weak opposed discharge. As a result, black luminance has been drastically reduced, and a dark-room contrast ratio of over 20,000:1, the highest ever reported, has been achieved.

This CEL material is fabricated by using a vapor-oxidation process that utilizes magnesium metal. CEL material consists of high-purity crystal particles of MgO that do not have doping impurities. Each particle is mainly a cubic single crystal. The distribution of the grain size is broad: from submicron to micron sized. The scanning-electron-microscopy (SEM) image of CEL material is shown in Fig. 1.

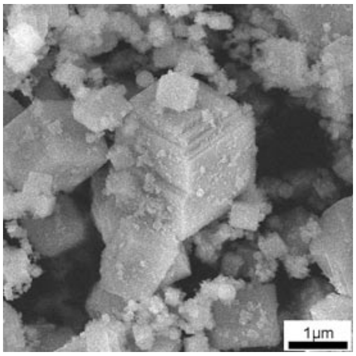



**FIGURE 1** — SEM image of CEL material.

## Discharge analysis of high-efficacy PDP with a luminous efficacy of 5 lm/W

**Toshiyuki Akiyama** (SID Member)
**Takashi Yamada** (SID Member)
**Masatoshi Kitagawa**
**Tsutae Shinoda** (SID Fellow)

*Advanced PDP Development Center Corp.*

***Abstract*** — The discharge mechanism concerning the width of the display electrodes in high-Xe-content gas mixtures to improve the luminous efficacy of PDPs has been researched. It was found that a luminous efficacy of 5 lm/W was realized for a high-Xe-content gas mixture and narrower display electrodes. For a high-Xe-content gas mixture, the luminous efficacy increases as the display electrode becomes narrower. This phenomenon was analyzed by observing the emission from a discharge cell. The observation data indicate that a high electron heating efficiency contributes to increased luminous efficacy along with narrow electrodes for a high-Xe-content gas mixture as well as high excitation efficiency.

Figure 2 shows the luminous efficacy as a function of the sustaining pulse voltage and width of the display electrode for a Ne + Xe20% gas mixture. A pulse cycle of 50 μsec is used in Fig. 2(a). All of the luminous-efficacy curves for a pulse cycle of 50 μsec have a peak with respect to the voltage. The voltages showing a peak efficacy increase as the width of the electrode gets narrower, and the peak efficacy simultaneously becomes higher. Among the pulse cycles, these characteristics shift to lower voltages with shorter pulse cycles.

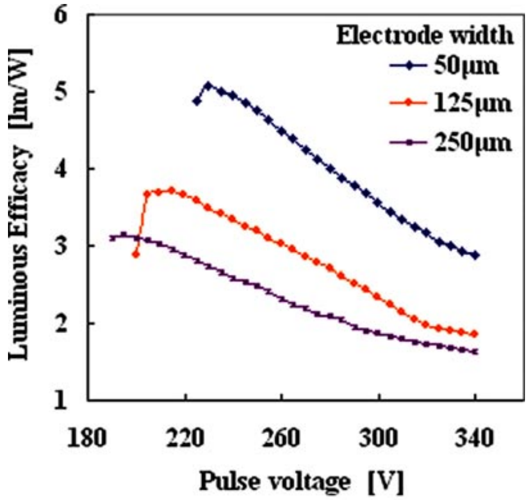



**FIGURE 2** — The luminous efficacy as a function of the sustaining pulse voltage for a pulse cycle of 50 μsec.

## Measurement of exo-electron emission from MgO thin film of ACPDPs

**Sang-Hoon Yoon** (SID Member)
**Cho-Rong Hong**
**Jae Jun Ko**
**Hee-Sun Yang**
**Yong-Seog Kim** (SID Member)

*Hongik University*

***Abstract*** — Exo-electron emission from MgO thin film was measured by attaching a high-precision current sensor to the address electrode of the rear plate of an ACPDP test panel. The measured results revealed that the exo-electron emission currents can vary very sensitively with the type of doping elements used in MgO film and the measuring temperature. The activation energy of the exo-electron emission estimated from the emission curves indicated that the trap levels are between 0.05 and 0.32 eV below the bottom of its conduction band. This suggests that shallow electron-trap levels within MgO film are mainly responsible for the exo-electron emission.

In ACPDPs, various forms of discharge energies, including UV and visible photon energy, kinetic and potential energies of electrons and ions irradiate the MgO surface. A fraction of these energies may be stored in MgO thin film in the form of trapped electrons and holes at the donor and acceptor levels, respectively. Therefore, the emission of exo-electrons from the MgO layer may occur through the relaxation process of those trapped charges. There is only little quantitative data available for the exo-electron emission from the MgO layer and its influence on the discharge characteristics of ACPDPs.

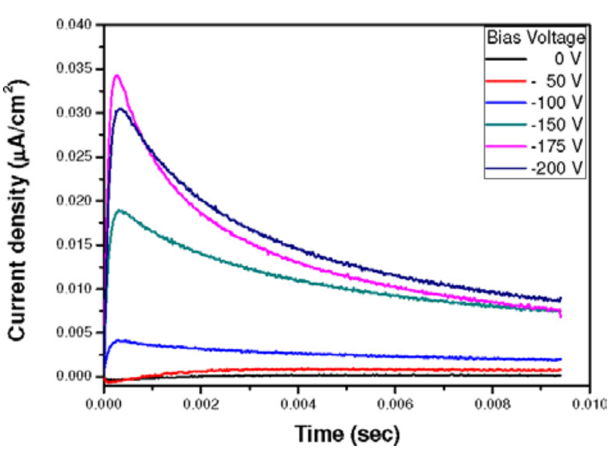



**FIGURE 3** — Effect of bias voltage between the sustain and address electrodes on exo-electron current density.

## Role of triplet–triplet annihilation in highly efficient fluorescent devices

**Denis Y. Kondakov** (SID Member)

*Eastman Kodak Co.*

***Abstract*** — A study of delayed electroluminescence in model highly efficient OLEDs based on anthracene derivatives indicate that triplet–triplet annihilation (TTA) contributes significantly to overall efficiency. Highly efficient devices (6–9% external quantum efficiencies) based on 9,10-bis(2-naphthyl)-2-phenylanthracene show that the TTA contribution depends primarily on operating current density, reaching as much as 20–30% of the overall emission intensity at moderate current densities (>5 mA/cm$^2$). Revision of the classical estimates of maximum external quantum efficiency of fluorescent OLEDs to 8% and maximum internal quantum efficiency to 40% is recommended to account for TTA contribution (even further revision may be necessary to account for a better-than-20% optical outcoupling).

The TTA process is of particular interest for OLED devices that utilize anthracene derivatives as emissive layer hosts, which can lead to high efficiencies and low operational voltages and also permit fabrication of blue-emitting OLED devices. The reasons why some OLED devices of this type exhibit EQEs far exceeding the theoretical maximum are not well understood. Although it is hypothetically possible that TTA makes a sufficiently high contribution to EQE to explain the exceedingly high efficiencies, no experimental evidence pro or contra has been reported.

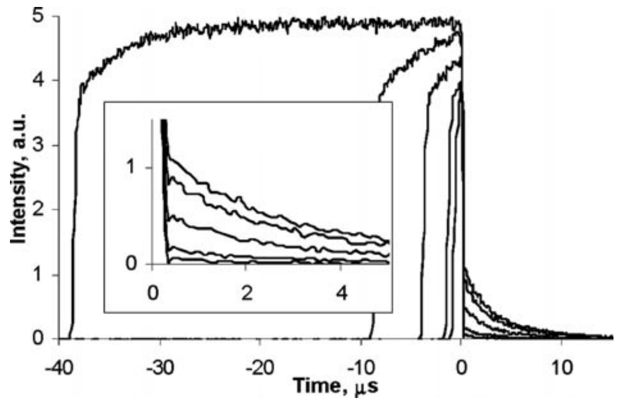



**FIGURE 4** — Time-resolved electroluminescence of device A1 as a function of excitation pulse width. The inset enlarges the initial part of the decays corresponding to 40-, 10-, 5-, 3-, and 2-μsec excitation pulse lengths, top curve to bottom curve, respectively.

## A 3.0-in. 308-ppi WVGA AMOLED with a top-emission white OLED and color filter

**Sangyeol Kim** (SID Member)
**Sunghun Lee**
**Mugyeom Kim** (SID Member)
**Jeongbae Song, Eokchae Hwang**
**Shinichiro Tamura** (SID Member)
**Sungkee Kang, Hyoseok Kim**
**Chiwoo Kim, Jinseok Lee**
**Jongmin Kim** (SID Member)
**Sungwoo Cho, Jaeyoung Cho**
**Min Chul Suh, Hyedong Kim**

*Samsung Electronics Co., Ltd.*

***Abstract*** — A 3.0-in. 308-ppi WVGA top-emission AMOLED display with a white OLED and color filters, driven by LTPS TFTs demonstrating a color gamut of >90% and a $\Delta(u', v')$ of <0.02, is reported. A white-emission source with a unique device structure was developed using all fluorescent materials and yielded efficiencies of 8.45% and 16 cd/A at 4000 nits with CIE color coordinates of (0.30, 0.32).

Figure 8 shows an image from the prototype panel. The resolution of the prototype panel is 308 ppi, which is the highest resolution for a full-color AMOLED panels ever reported. In addition, all of the deposition processes only use an open mask, and the thickness of each layer from anode to cathode at each red, green, and blue subpixel is the same. Therefore, the thickness of the white-light-emitting organic layers corresponding to the RGB subpixels is the same, and this panel architecture is obviously favorable for mass production.

**FIGURE 8** — 3.0-in. 308-ppi WVGA AMOLED prototype panel using a top-emission white OLED with color filters.

## Micro-cavity design of bottom-emitting AMOLED with white OLED and RGBW color filters for 100% color gamut

**Baek-woon Lee** (SID Member)
**Young-gu Ju**
**Young In Hwang**
**Hae-yeon Lee**
**Chi Woo Kim**
**Jin Seok Lee**
**Jun Hyung Souk** (SID Member)

*Samsung Electronics Co., Ltd.*

***Abstract*** — Two optical structures used for a bottom-emitting white organic light-emitting diode (OLED) is reported. An RGBW color system was employed because of its high efficiency. For red, green, and blue (RGB) subpixels, the cavity resonance was enhanced by the use of a dielectric mirror, and for the white (W) subpixel, the mirror was removed. The optical length of the cavities was controlled by two different ways: by the thickness of the dielectric filter on top of the mirror or by the angle of oblique emission. With both methods, active-matrix OLEDs (AMOLEDs) that reproduced a color gamut exceeding 100% of the NTSC (National Television System Committee) standard were fabricated. More importantly, the transmission of a white OLED through R/G/B color filters was significantly higher (up to 50%) than that of a conventional structure not employing a mirror, while at the same time as the color gamut increased from ~75 to ~100% NTSC.

The thicknesses of the layers are determined in the following order. First, the thicknesses of the bottom-most IZO/ITO and SiOx layers are set to a quarter-wave. A 600 Å of IZO was used. Then, the thickness of the anode (the top-most IZO/ITO layer) is determined so that the combined thickness of the anode and the bottom-most IZO/ITO layer yield the best performance for the W subpixels. The white emitter was optimized for the total IZO thickness at 900 Å. Therefore, the thickness of the anode was determined to be 300 Å. The optimal green condition is determined by the thickness of the common $SiN_x$ layer. Last, the simultaneous R and B condition is satisfied by the thickness of the intermediate "filter" IZO/ITO layer.

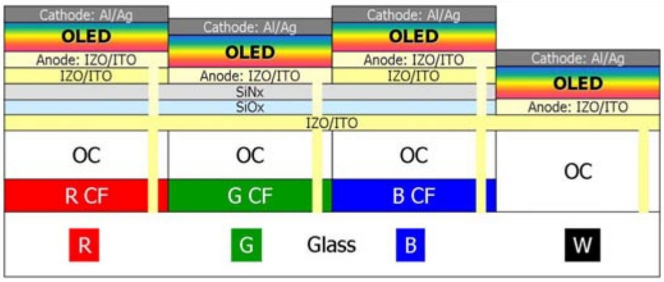



**FIGURE 5** — A micro-cavity design of a RGBW bottom-emitting AMOLED (Design 1). OC stands for overcoat. The RGB subpixels have DBR (IZO or ITO and $SiO_x$), a filter common for RGB ($SiN_x$), and another filter (IZO or ITO) for R and B subpixels. The W subpixels do not have DBR in order to avoid the spectral modification and dependence on the viewing angle.

## Printable phosphorescent organic light-emitting devices

**Sean Xia** (SID Member)
**Kwang-Ohk Cheon**
**Jason J. Brooks** (SID Member)
**Mark Rothman, Tan Ngo**
**Patrick Hett, Raymond C. Kwong**
**Mike Inbasekaran** (SID Member)
**Julie J. Brown** (SID Member)
**Takuya Sonoyama, Masaki Ito**
**Shunichi Seki, Satoru Miyashita**

*Universal Display Corp.*

***Abstract*** — A new approach to full-color printable phosphorescent organic light-emitting devices ($P^2OLEDs$) is reported. Unlike conventional solution-processed OLEDs that contain conjugated polymers in the emissive layer, the $P^2OLED$'s emissive layer consists of small-molecule materials. A red $P^2OLED$ that exhibits a luminous efficiency of 11.6 cd/A and a projected lifetime of 100,000 hours from an initial luminance of 500 cd/m$^2$, a green $P^2OLED$ with a luminous efficiency of 34 cd/A and a projected lifetime of 63,000 hours from an initial luminance of 1000 cd/m$^2$, a light-blue $P^2OLED$ with a luminous efficiency of 19 cd/A and a projected lifetime 6000 hours from an initial luminance of 500 cd/m$^2$, and a blue $P^2OLED$ with a luminous efficiency of 6.2 cd/A and a projected lifetime of 1000 hours from an initial luminance of 500 cd/m$^2$ is presented.

Figure 10 shows the EL spectra and emission images of red and green $P^2OLED$ pixels fabricated by ink-jet printing. The spectra measured from the ink-jet-printed devices were identical to that of the spin-coated devices, indicating that the emission was purely from the phosphorescent dopant. In addition, absence of bright spots and an irregular emission pattern indicated that there was no phase separation or recrystallization. Despite the promising initial performance, the ink-jet-printed $P^2OLEDs$ exhibited lower operational stability compared to that of spin-coated devices.

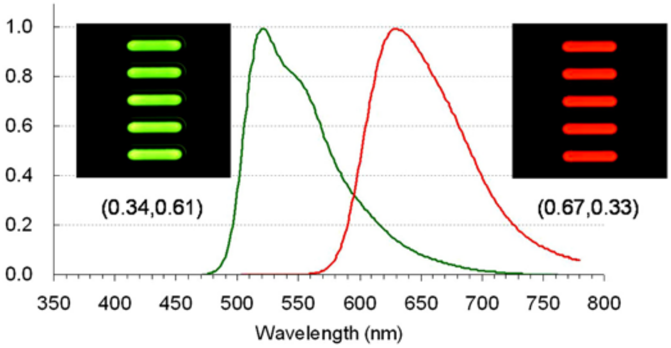



**FIGURE 10** — Electroluminescence spectra and images of green and red $P^2OLED$ pixels by ink-jet printing.

# White stacked OLED with 38 lm/W and 100,000-hour lifetime at 1000 cd/m$^2$ for display and lighting applications

**Gufeng He**
**Carsten Rothe**
**Sven Murano**
**Ansgar Werner** (SID Member)
**Olaf Zeika**
**Jan Birnstock** (SID Member)

*Novaled AG*

***Abstract*** — The three critical parameters in determining the commercial success of organic light-emitting diodes (OLEDs), both in display and lighting applications, are power efficiency, lifetime, and price competitiveness. PIN technology is widely considered as the preferred way to maximize power efficiency and lifetime. Here, a high-efficiency and long-lifetime white-light-emitting diode, which has been realized by stacking a blue-fluorescent emission unit together with green- and red-phosphorescent emission units, is reported. Proprietary materials have been used in transport layers of each emission unit, which significantly improves the power efficiency and stability. The power efficiency at 1000 cd/m$^2$ is 38 lm/W with CIE color coordinates of (0.43, 0.44) and a color-rendering index (CRI) of 90. An extrapolated lifetime at an initial luminance of 1000 cd/m$^2$ is above 100,000 hours, which fulfils the specifications for most applications. The emission color can also be easily tuned towards the equal-energy white for display applications by selecting emitting materials and varying the transport-layer cavities.

The basic layered structure of a standard bottom-emission PIN OLED consists of a transparent anode (ITO)/*p*-type-doped hole-transport layer (HTL)/interlayer at the hole side (EBL)/emission layer (*e.g.,* matrix with phosphorescent or fluorescent emitters)/interlayer at the electron side (HBL)/*n*-type-doped electron-transport layer (ETL)/metallic cathode (Al) [see Fig. 3(a)]. Since each PIN OLED starts from a highly *p*-type electrically doped HTL and ends with a highly *n*-type-doped ETL, one PIN OLED was simply stacked on top of another PIN OLED without any intermediate layer. Figure 3(b) shows an example of stacked OLEDs with red, green, and blue emission units to generate white light. The *n*-type-doped ETL, in one emission unit, is in contact with the *p*-type-doped HTL in the subsequent emission unit to form a doped so-called organic *p*–*n* junction.

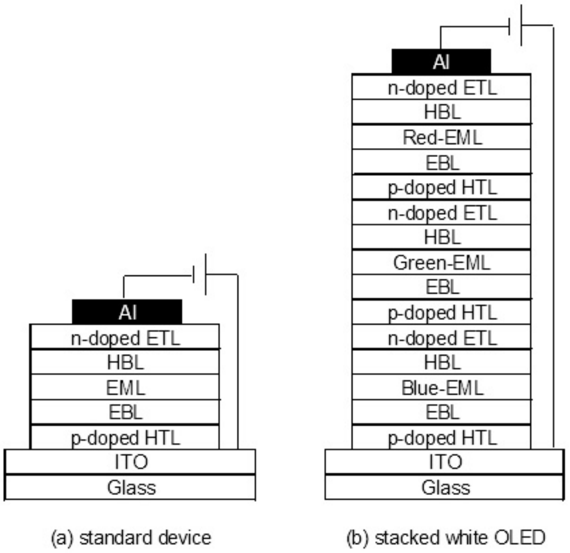
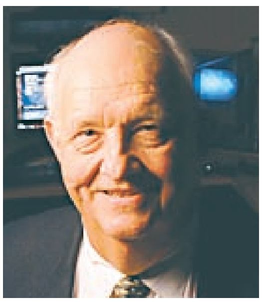



**FIGURE 3** — Schematic architectures of (a) standard PIN OLED and (b) stacked white OLED.

## In Memorium
### James L. Fergason Remembered


*James L. Fergason*

We were saddened to hear that Dr. James L. Fergason passed away on December 9, 2008. Jim is widely recognized as one of the leading independent inventors of the past 50 years and as the father of the modern liquid-crystal industry. His technical insights, leadership, creativity, optimism, and hard work led him on a life-long path of major technology contributions. His breakthrough products still employ hundreds of thousands of people and contribute billions of dollars to the world economy. Along the way he found time to mentor independent inventors, contribute to patent reform, and love his wife of over 52 years, as well as their four children and 10 grandchildren.

An active inventor, Fergason was awarded more than 150 U.S. patents and 500 foreign patents and was inducted into the National Inventors Hall of Fame in 1998. Although he didn't discover liquid crystals, he did become one of the first to understand what they could do, and he invented some of their practical uses, including digital watches, calculators, forehead thermometers, and flat-panel TVs.

Shortly after earning his undergraduate degree from the University of Missouri in 1956, Fergason accepted a position as a researcher at Westinghouse Research Laboratories in Pennsylvania, where he formed and led the first industrial research group to study liquid crystals. At Westinghouse, he spent most of his time observing liquid crystals and understanding how they worked. His pioneering efforts earned him the first patent on the practical use of cholesteric liquid crystals, which he filed in 1958 and received in December 1963.

In the late 1960s, the Liquid Crystal Institute at Kent State University in Kent, Ohio, recruited Fergason for his fundamental understanding of cholesteric liquid crystals. While he was associate director of the Institute, his work on the twisted-nematic field effect of liquid crystals evolved and became a critical step in his career of continuous inventions and innovations in the flat-panel-display industry.

In 1970, Fergason started his own company, the International Liquid Crystal Company (Ilixco), to further study and commercialize LCDs. During the 1980s and 1990s, he led self-funded research and technology incubation programs in which he and his teams focused on the challenges of liquid crystals and display technology. Subsequently, he was issued several enabling patents for the twisted-nematic LCD, the principal technology used in the vast majority of flat panels today. Fergason ultimately sold these patents to Hoffman LaRoche in exchange for a share of the royalty stream from a portfolio of patents that was successfully licensed to nearly all LCD makers.

In 1983, he was issued a patent for the fast-switching-speed "surface mode" LCD, which was licensed to multiple manufacturers for use in high-speed shutters. He won a notable litigation against Tektronics related to this technology. Also, in the early 1980s, Fergason invented the PDLC-mode LCD that enabled a new family of plastic-substrate flat panels as well as switchable windows. He licensed the PDLC portfolio to Raychem Corp. and supported its commercialization program for several years.

In 2001, he founded Fergason Patent Properties LLC to broadly license all of his intellectual property on a non-exclusive basis and support licensees in integrating inventions into new and improved products. He set up his own development laboratories and evolved patent portfolios in several new areas, including image-synchronized brightness control, definition doubling, and 3-D visualization displays.

His inventions have had ongoing economic impacts. His twisted-nematic LCD is a critical element of the technology that has enabled the explosive growth of the mobile information, communications, and entertainment services, as well as the related consumer-electronics equipment markets that are a cornerstone of the world economy.

Jim's achievements were widely recognized and he received many honors, including the SID Frances Rice Darne Memorial Award, the Richardson Medal from the American Optical Society, induction into the Inventors Hall of Fame, and the Lemelson-MIT Prize – the highest award offered anywhere in the world for invention. Other recognitions came from the University of Missouri, his alma mater, with an Honorary Doctorate, and also from Kent State University and the Smithsonian Institute.

Through his alliances with the U.S. Patent Office, Inventors Hall of Fame, SPIE (Society of Photographic Instrumentation Engineers), OSA (Optical Society of America), and other professional organizations, he mentored independent inventors. Serving on the United States Patent and Trademark Office's advisory board, he supported efforts to improve the quality of patents.

Throughout Jim's life, Dora, his wife, stood beside him and supported his career and their family. He was a loving father and doting grandfather. Jim is survived by Dora and their four children, Teresa, Jeffrey, John, and Susan as well as by 10 grandchildren.

*Sources for this article include Insight Media, Lemelson–MIT Program, National Inventors Hall of Fame, and Fergason Patent Properties LLC.*

## New Senior Members

The following SID members were elevated to SID Senior Member status on November 16, 2008:

Edward Buckley
David Eccles
Gary Jones
Kalil Käläntär
Sungkyoo Lim
John Rupp

The following SID members were elevated to SID Senior Member status on January 18, 2008:

Birendra Bahadur
T. N. Ruckmongathan

## LatinDisplay Takes Place in Brazil

The Latin America SID Chapter hosted LatinDisplay 2008 in Campinas, Brazil, last November 17–20, 2008. The key goals of this conference were to cover the most recent advances and trends in displays and to encourage open discussions about needs, opportunities, and the fostering of cooperative R&D programs in the Ibero-American region.

*Digital student desks equipped with laptop and tablet were shown at LatinDisplay 2008 and also featured, as part of a follow-up event (shown here), the Display Escola (display school), which was organized by the Associação Brasileira de Informática (ABINFO).*

In the hopes of attracting more participants this year, the organizers also welcomed papers on solar cells. "This hope materialized," says Daniel den Engelsen, Chairman of the Program Committee of LatinDisplay 2008 and Senior Scientist at Associação Brasileira de Informática (ABINFO) and Centro de Tecnologia e Informação Renate Archer. The number of participants was 226, 37 more than last year, or an increase of 20%. By far the majority of the participants (151) came from the State of São Paulo; 40 came from other states of Brazil; and 35 came from abroad, the largest group (12) from the U.S.

LatinDisplay featured 23 invited speakers from Brazil, USA, The Netherlands, India, Italy, Finland, Germany, Japan, and Singapore. Among those, the following focused particularly on markets and market opportunities for the display industry in Brazil: "Present and emerging mobile multimedia display technology" by Jyrki Kimmel (Nokia); "Solar cell market and technology" by Gopalan Rajeswaran (Moserbaer); "Brazil: the alternative for the display industry" by Margarida Baptista (BNDES); "LCD & photovoltaic market outlook" by Anis Fadul (Corning); and "Display market and trends" by John Jacobs (DisplaySearch). A follow-up discussion led by Ken Werner of Insight Media focused on how Brazil could attract manufacturing in the areas of displays and solar cells.

Den Engelsen notes that from an industrial point of view, the role of Latin America is insignificant in the display arena: "The center of gravity of display production is in the Far East," he says, "whereas the new innovations on 3-D displays and flexible displays are largely coming from Europe and the U.S. However, in applications, Latin America is playing a role."

One such application that received a great deal of attention at the conference is the digital student desk equipped with PC and tablet, as discussed by Dr. Victor Mammana (CTI) in his presentation, "Using tablets for education in digital desks."

"This is a Brazilian innovation," says den Engelsen, "and it is getting momentum now in Brazil and also abroad."

## erratum

In the last row of Table 1 appearing on page 13 of the December 2008 issue, the correct spelling of the supplier is bTendo and the correct resolution in the same row is WVGA. We apologize for any confusion that this may have caused.

– Editor-in-Chief

## president's corner

*continued from page 6*

So, crises and deadline offer an opportunity to make decisions that might be difficult to make in good times. Sometimes this works out, and sometimes it doesn't. What is certainly true is that economic cycles (and deadlines) change behavior – it is up to each of us to determine how we respond. Focus, and think, before acting.

In my case, it's worked out OK. This column is done, and I can get back to my other urgent issues. I hope everyone else's crises turns out well.

Paul Drzaic
President
Society for Information Display



## editorial

*continued from page 2*

architectures, and drive electronics. Today, in fact, there are several major semiconductor companies offering single-chip driver solutions for LED arrays, a major enabling factor from a segment of our industry that rarely supports niche applications. They know where this is heading, and so do we. This is a significant growth opportunity for the adopting and enabling companies and we'll be here watching. We're very grateful to David for all his work in preparing this issue and hope you enjoy reading it as much as we did putting it together.

Change has also taken place very close to home. This month we welcome our new Managing Editor, Jenny Donelan. Jenny brings with her a wide range of publishing and editing experience, having previously managed both *Computer Graphics World* and *BYTE* magazines, and she has built a strong portfolio as a freelance writer and editor. Jenny will be responsible for all in-house content creation as well as the final editing and preparation of our normal monthly features. She gets her start this month not only in building this issue but also in giving you a glimpse into all the great offerings in San Antonio for this year's Display Week travel guide. We enthusiastically welcome Jenny and hope that she has found here a working home she can be comfortable in for a long time.

– Stephen Atwood

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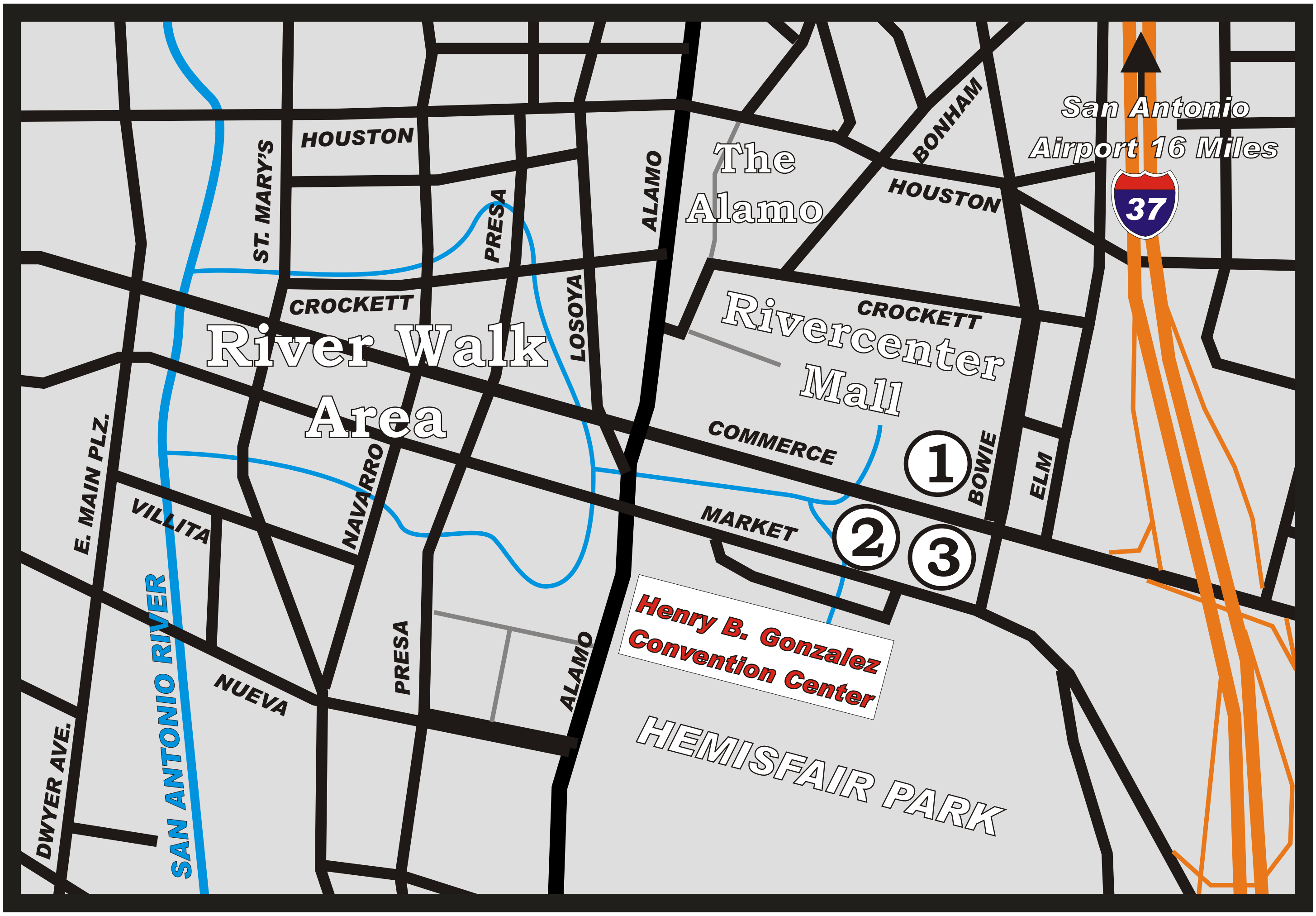


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