OLED ISSUE

Information DISPLAY

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Phosphorescent OLEDs Appear in Products

- **Phosphorescent OLEDs**
- **AMOLED Backplanes: a-Si vs. Poly-Si**
- **Comparative Value Growth Trends**
- **Impulse Driving Methods for AMLCDs**
- **Consumer Electronics Show Report**

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This Fujitsu cellular telephone incorporates a 1.1-in.-diagonal 96 × 72-pixel 4096-color sub-display from Pioneer. The sub-display incorporates UDC's red-emitting phosphorescent-OLED technology.

Javi Lavandeira

Next Month in
Information Display

Displays for Portable Products
- Palmtop TV
- Displays for HDTV
- Manufacturing Small- and Medium-Sized Displays
- Standardizing Display Interfaces for Mobile Telephones
- ASID '04 Report

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editorial

A Park in Nanjing

A huge industrial park – actually, a linked group of industrial parks – is under construction in the north-eastern suburbs of Nanjing, China, south of the Yangtze River. A large deep-water port, completely separate from the port for the city of Nanjing, has been built on the Yangtze to service it. The industrial parks are part of NETDZ – the Nanjing Economic and Technological Development Zone.

NETZD covers an area of 13.37 square kilometers, much of it still not developed. But a lot of it is, with newly completed buildings and buildings still under construction visible over a large area, as are expanses of leveled land ready for construction. There are 1150 enterprises in NETZD, 225 of them funded by non-Chinese companies from 20 countries; 96 of the projects have drawn an investment of over US$10 million each. Total investment thus far is US$2.7 billion, with roughly two-thirds of that total in contracts and one-third in operations.

I visited NETZD, and particularly its "Nanjing Korea Industrial Park," along with Myung Hwan Oh (Dankook University), Jin Jang (Kyung Hee University), and some employees of LG.Philips LCD (Seoul), which has a new TFT-LCD module assembly plant there. Construction of LG.Philips LCD's Nanjing building began in August 2002, and trial production started on April 14, 2003. This nine-month cycle is clearly a source of pride for Jong Seon Choi, Vice President of LG.Philips LCD (Nanjing), and was reportedly considered amazing by local standards.

The plant has 1000 employees, and production is round-the-clock in three shifts. Full capacity (on four lines) is 400,000 modules per month, although current output is less because of a shortage of TFT-LCD glass, Choi said. The plant also makes LCD monitors. I asked Choi if the scale of development made it hard to find good technical staff in Nanjing. "No," he said, "it is not a problem. There are many good universities in Nanjing."

The components for the assembly operation all come from Korea. These include the TFT-LCD glass, polarizer, TAB ICs, and printed-circuit board. The components for the backlight unit (BLU) come from Korea, but they are assembled by an independent company located in the NETDZ.

Module assembly is the leading edge of advanced display manufacturing in China. Labor-intensive and with relatively modest capital requirements, it is a sensible first step toward TFT-LCD manufacturing. (LG.Philips LCD's capital investment in its Nanjing plant is $31 million; its total investment is $77 million.) Taiwan display maker HannStar also has a module assembly plant in the NETDZ.

LG.Philips LCD is not the only LG company located in the NETDZ. In fact, along LG Road is, among others, an LG Chemical plant devoted to making polarizers and separate LG Electronics plants devoted to making PDP TVs and monitors.

The size of the Nanjing Economic and Technological Development Zone and the energy and commitment with which it is being developed are impressive. For the manufacture of advanced displays in China, it is clear that such activities are just the beginning.

– KIW

We welcome your comments and suggestions. You can reach me by e-mail at kwerner@nutmegconsultants.com, fax at 203/855-9769, or phone at 203/853-7069. The contents of upcoming issues of ID *are available on the SID Web site (http:// www.sid. org).*

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my turn

LCD Panels Need More Class

by Alfred Poor

A customer shells out good money for an LCD monitor (or a notebook with an LCD screen), turns it on, and discovers a couple of tiny colored dots that continue to glow even when the screen is supposed to show black. The immediate reaction is "I've got a defective unit," and the user tries to exchange it for one without defects – only to be told by technical support that such defects are normal with LCD panels and the company will not exchange it. The user is unhappily surprised.

The good news is that product manufacturers now are making more of an effort to explain their pixel-defect policies up front to consumers, in the user manuals and on Web sites. The bad news is that it is not always easy for end users to understand. As an example, the following policy from an unnamed company was selected at random.

"The LCD monitor shall not show more than (whichever of the following limits is reached first):

- A total of eight non-performing pixels (of whatever type), or
- Five bright non-performing pixels appearing as a red, green, blue, yellow, cyan, magenta, or white dot on a dark or black background, or
- Five dark non-performing pixels appearing as a black dot on a bright or white background, or
- Two non-performing pixels of any type located less than 10 mm from each other."

If you are not a display-industry insider, I doubt that this will make much sense to you. And how do you compare this to the claims of other LCD manufacturers?

Another manufacturer claims in its end-user manual that the panels used in its 1280 × 1024-pixel monitor are at least 99.999% free of stuck pixels. But given the 3,932,160 subpixels on the panel (a number that they also cite in the manual), this still means that there could be as many as 39 stuck subpixels and the monitor would still comply with this quality statement. Would an end user understand this enough to be able to compare the quality policies of these two companies?

When we buy beef or butter at the grocery store, we can see right on the outside of the package whether the product is Grade A or Choice or something else. Why can't LCD-panel products have similar consumer labeling so buyers can compare quality standards more easily? What we need is a consumer-oriented classifying system that product makers can use to advertise the quality of the panel used in their display products.

But wait! Such a system already exists. The ISO 13406-2 standard specifies a variety of attributes for LCD panels, including a classification system for pixel defects. Class I panels have zero defects, period. Class II panels quantify the number of permissible defects per million pixels. Qualifying panels can have up to two bright pixel defects, two dark pixels, and up to five subpixel defects, either bright or dark. Two or more defects within a 5 × 5-pixel matrix are not permitted.

continued on page 42

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OLED Excitement

Phosphorescent-OLED technology, with its high luminous efficiency, is the key to OLED penetration of the display and lighting markets, and in other markets as well.

by Mike Hack and Julie J. Brown

THIS YEAR will be an exciting one for organic light-emitting-diode (OLED) technology. At the end of 2003, a number of manufacturers, including Pioneer, RiTdisplay, Philips, SNMD, and TECO, were making passive-matrix OLED displays, and the Sanyo–Kodak joint venture was shipping an active-matrix OLED (AMOLED) product. According to Barry Young of DisplaySearch, worldwide sales for the year reached about $250 million, with the majority coming from sales of passive-matrix cellular-telephone subdisplays.

As this article goes to press, a number of additional companies will have announced plans to launch OLED products; annual sales this year are expected to exceed $500 million, with an even mix of passive- and active-matrix products. In fact, many major active-matrix liquid-crystal-display (AMLCD) manufacturers have installed or are about to install OLED-manufacturing equipment and are scheduled to launch AMOLED products in the near future.

The rapid growth of OLEDs is largely due to the advantages that they offer compared to AMLCDs for mobile applications and their promise for large-area displays. OLED displays produce very attractive images. The light emission from OLEDs is bright, and they produce saturated colors, with color gamuts 70–75% that of the NTSC standard gamut, compared to the 40–60% that is typical of AMLCDs designed for low-power mobile devices.

OLED pixel response times are less than 0.1 msec, and Lambertian emission creates inherently wide viewing angles. Combined, these features make OLEDs highly desirable for showing full-color video-rate images. OLEDs are also thinner and lighter than AMLCDs, giving them additional advantages for mobile-device applications. For example, they require only a single substrate, instead of the two layers required by liquid-crystal technology.

A major concern about OLEDs has been their lifetime in commercial-product applications. Fortunately, tremendous improvements have been recorded by various groups worldwide; the latest advances offer operational lifetimes in the tens of thousands of hours at display-level luminances.

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Building a Better OLED

If OLED displays are to capture a significant market share of the current glass-based flat-panel-display (FPD) business, it is not sufficient to be thinner and lighter and offer better image quality. The technology must also surpass that of AMLCDs in terms of cost and power consumption. A major step in this direction has been achieved by the pioneering work on phosphorescent-OLED (PHOLED™) technology at Universal Display Corp. (UDC), in close collaboration with research partners at Princeton University and the University of Southern California. Initially, PHOLED displays will be used in mobile devices, and then in larger-area applications such as TVs, which will help establish a manufacturing base for visionary products based

Table 1: The current performance of a subset of UDC's PHOLED devices. UDC is actively pursuing a long-lived saturated phosphorescent blue-emitting device.

PHOLED Name	RD15	RD07	GD33	BD58	BD30
Color					
CIE (x, y)	0.67, 0.33	0.65, 0.35	0.31, 0.64	0.16, 0.38	0.14, 0.21
Luminous Efficiency (cd/A) at xxx cd/m^2	11 at 500	15 at 500	29 at 1,000	30 at 100	19 at 100
Lifetime (hours)	35,000 @ 500 cd/m^2	22,000 @ 500 cd/m^2	20,000 @ 1,000 cd/m^2	<1,000 @ 200 cd/m^2	<1,000 @ 200 cd/m^2

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Fujitsu

***Fig. 1:** The Fujitsu F505iGPS cellular phone uses a Pioneer full-color passive-matrix sub-display that incorporates UDC's red-emitting PHOLED material. The sub-display has a 1.1-in. diagonal, 96 × 72 pixels, and 4096 colors.*

on transparent and flexible (roll-out) display devices.

PHOLEDs are up to four times more efficient than the conventional fluorescent-OLED devices, so they can consume as little as one-fourth the power. As a result, the power consumption of an active-matrix display in video-rate applications can be less than that of an equivalent backlit AMLCD. An additional benefit of high efficiency is that drive currents are low: a few microamps per display pixel. The low drive current reduces the backplane carrier requirements, so that amorphous-silicon (a-Si) transistor technology – and eventually organic thin-film transistors (OTFTs) – may be used successfully. Conventional fluo-

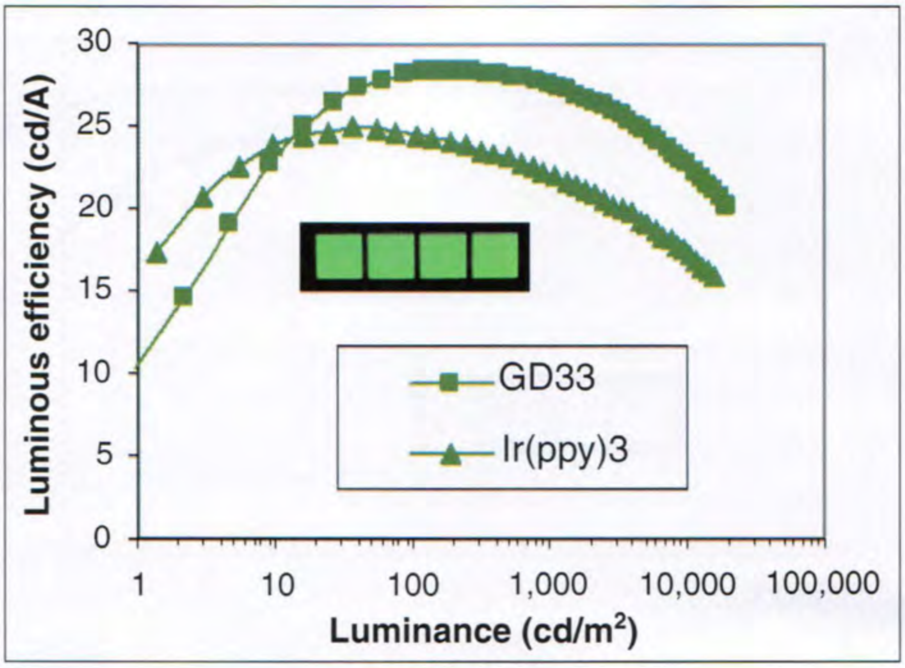

***Fig. 2:** The improvement in luminous efficiency (cd/A) vs. luminance (cd/m^2) of two green-emitting PHOLED devices having CIE coordinates of (0.30, 0.63) is attributed to the use of GD33, a new Gen 2 UDC PHOLED dopant.*

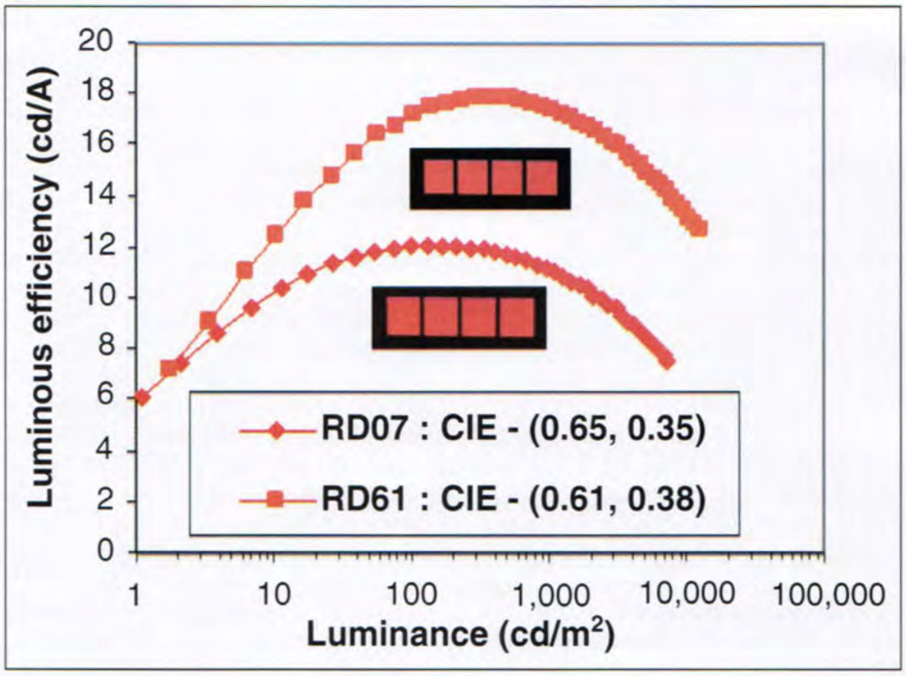

***Fig. 3:** The improved luminous efficiency (cd/A) vs. luminance (cd/m^2) is attributed to the use of two new red-emitting PHOLED devices (RD07 and RD61).*

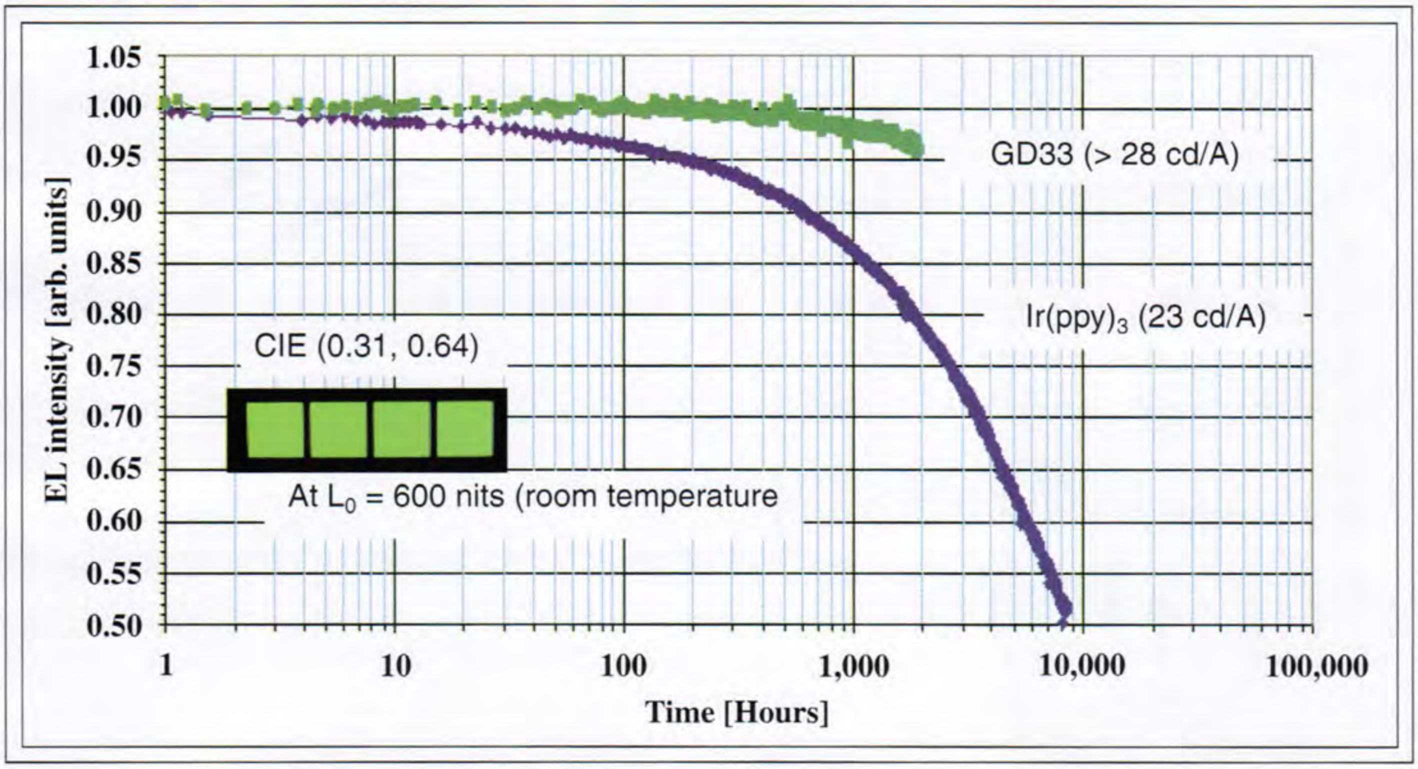

Fig. 4: The luminance vs. lifetime at room temperature of two green-emitting PHOLED devices, $Ir(ppy)_3$ and GD33, starting at an initial luminance of 600 cd/m^2, indicates improved lifetime.

rescent-OLED devices must often be designed to use low-temperature-polysilicon (LTPS) backplanes.

The use of a-Si backplanes will lead to substantial cost reductions in the manufacture of AMOLED displays, particularly for larger-sized applications, in which the panel cost is substantially greater than the cost of the driving electronics. A mature a-Si TFT infrastructure already exists for AMLCDs, and the larger substrate sizes (which approach 2 m square) offer better efficiency than that provide by LTPS production, which is currently limited to substrates less than 1 m square. Estimates by AU Optronics (AUO) suggest that a-Si backplanes will be half the cost of their LTPS counterparts.

How PHOLEDs Work

The first efficient OLED devices were demonstrated by Tang and Van Slyke of Eastman Kodak Co. in the 1980s. In these fluorescent small-molecule OLEDs, light emission occurs as a result of the recombination of singlet excitons. The internal quantum efficiency is limited to approximately 25%.

In contrast, PHOLEDs are much more energy efficient, and are based on the work of Steve Forrest and Mark Thompson of Princeton University and the University of Southern California, respectively. In the phosphorescent system, all excitons may be converted into triplet states through intersystem crossing around a heavy-metal atom. These triplet states emit radiatively, enabling the extremely high efficiencies (Table 1).

The next generation of high-efficiency PHOLED devices is under development, not only for vacuum-deposited devices, but also for other manufacturing processes. These include organic vapor-phase deposition (OVPD), in collaboration with Aixtron AG, and solution processing, in collaboration with DuPont Displays. The later would make it possible to "print" displays using ink-jet-printing technology.

Research continues to improve materials and device architecture. Recently, the development of blue phosphorescent emission (CIE = 0.14, 0.23) was reported, but lifetime still remains a challenge. Given the threefold increase in efficiency that organic phosphorescent devices offer over their fluorescent counterparts, these new OLEDs provide improved performance in applications from simple icon monochrome displays to full-color passive-matrix displays and high-resolution full-color active-matrix displays. Recently, Pioneer Corp. began commercial production of a full-color passive-matrix sub-display for the Fujitsu F505iGPS cellular telephone, which incorporates UDC's red-emitting PHOLED material (Fig. 1).

Phosphorescent emission enables OLED internal quantum efficiencies to approach 100%, as compared to an approximate 25% maximum for conventional fluorescent devices. The luminous efficiency *vs.* luminance of a recently developed Gen 2 GD33 PHOLED device shows significant gains over a Gen 1 green-emitting phosphorescent device – GD29 [$Ir(ppy)_3$] – and has both longer lifetime and higher efficiency (Fig. 2). For small-area active-matrix displays, typical luminances of green subpixels will be in the range of 100–1000 cd/m^2, and for passive-matrix applications the subpixel luminance is in the range of 10,000–50,000 cd/m^2.

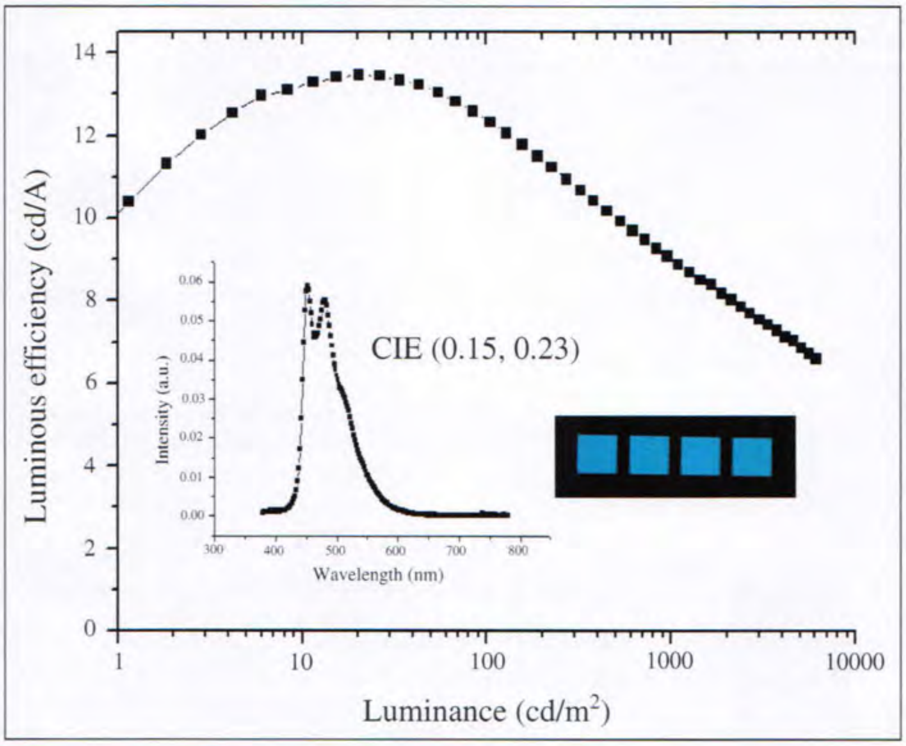

Fig. 5: The luminous efficiency (cd/A) vs. *luminance (cd/m²) of a blue-emitting PHOLED material with CIE coordinates of (0.14, 0.23) indicates improved performance. The electroluminescent response is shown in the inset.*

The first-generation green-emitting PHOLED devices based on the phosphorescent dopant fac-tris(2-phenylpyridine) iridium $[Ir(ppy)_3]$ exhibited a luminous efficiency of 22–24 cd/A for active-matrix applications and 13–17 cd/A for passive-matrix displays. As can be seen, in the second-generation GD33 PHOLED devices, the efficiency has been improved to levels of 28 cd/A for active-matrix applications and 18–22 cd/A for passive-matrix displays, and progress is continuing.

In comparison, fluorescent green-emitting devices perform in the range of 7–15 cd/A in active-matrix applications. This improvement in green-emitting PHOLED technology is the result of both improved materials systems and device design. Table 1 shows the very good lifetimes that have now been achieved using green- and red-emitting PHOLED devices, and through ongoing development, PHOLED lifetimes and efficiencies are continually being improved. Previously published articles and papers have reported luminous efficiencies approaching 70 cd/A for green-emission-based devices, but the new devices described here also have very long operational lifetimes.

The luminous efficiency *vs.* luminance for two different PHOLEDs in the red-emitter family show additional improvements (Fig. 3). In fluorescent displays, the red subpixel generally consumes the most power; for this reason, considerable effort has been focused on red-emitting phosphorescent devices. The saturated red emitter (RD07 PHOLED) has a luminous efficiency of about 15 cd/A for active-matrix displays and 8–10 cd/A for passive-matrix applications. To further reduce the power consumption of full-color displays, a less-saturated red emitter

➤ Current (30% on, @100 Cd/m²) : 200mW, Target: <100mW

Color	Fluorescent System				Phosphorescent System (1)				Phosphorescent System (2)			
	x	y	Effi. (cd/A)	Power (w)	x	y	Effi. (cd/A)	Power (w)	x	y	Effi. (cd/A)	Power (w)
Red	0.60	0.38	5.1	**0.41**	0.65	0.35	5.6	**0.25**	0.61	0.38	13.6	**0.12**
Green	0.30	0.65	13	**0.17**	0.27	0.62	22	**0.09**	0.27	0.62	22	**0.08**
Blue	0.14	0.16	4.7	**0.26**	0.14	0.16	5.7	**0.20**	0.14	0.16	5.7	**0.20**
White	0.31	0.32	-	**0.84**	0.31	0.32	-	**0.54**	0.31	0.32	-	**0.40**

❖ 100 Cd/m² (with Circular Pol.), 100 % of Pixels on

Power Consumption Ratio

Fig. 6: Incorporating PHOLED technology into a full-color AMOLED display fabricated by Samsung SDI results in markedly reduced power consumption. (Photograph and chart courtesy of H. K. Chung, Samsung SDI.)

Size	4 in.
Pixel Size	171(×3)×264 μm
Resolution	160(×RGB)×234
Color	262K
Peak Brightness	300 cd/m²
Contrast Ratio	>300 : 1
Power Consumption	670 mW (video images)

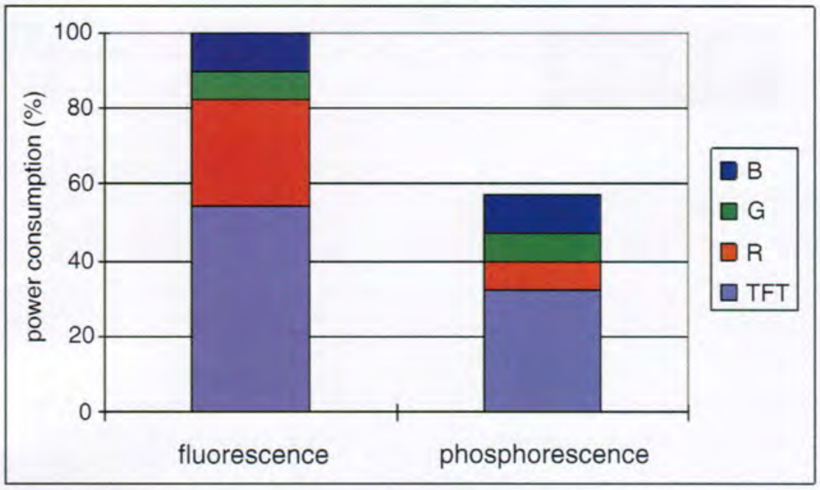

Fig. 7: An AMOLED fabricated by AU Optronics incorporates UDC's red-emitting PHOLED technology, as demonstrated at the 2002 SID International Symposium.

(RD61 PHOLED) has been developed having efficiencies of 22–24 cd/A in active-matrix applications and 15–20 cd/A in passive-matrix applications. By comparison, the typical red-emitting fluorescent devices produce luminous efficiencies of 2–5 cd/A for active-matrix displays. More recently, a deeper-red-emitting PHOLED with CIE coordinates of (0.67, 0.33) has been developed. It has good efficiency of more than 11 cd/A and an operational lifetime well over 35,000 hours at initial luminances of more than 500 cd/m².

In addition to device efficiency, operational stability is also a key performance requirement. The operational lifetime of the GD33 PHOLED device is much improved over the first-generation $Ir(ppy)_3$ PHOLED devices (Fig. 4). The device lifetime is measured at room temperature in packaged test devices under constant dc-current drive conditions. The second-generation green-emitting PHOLED exhibits device lifetimes to half-brightness of greater than 20,000 hours at an initial luminance of 1000 cd/m².

To further reduce display power consumption, there is a significant effort to develop saturated phosphorescent blue-emitting OLEDs with long operational lifetimes. Recent progress has shown that the attainment of highly efficient blue-emitting devices is possible. For example, a new device system has peak luminous efficiencies greater than 19 cd/A at a luminance of 200 cd/m² with CIE coordinates of (0.14, 0.21) (Fig. 5). UDC has also demonstrated a light-blue-emitting PHOLED having CIE coordinates of (0.16, 0.38), a luminous efficiency exceeding 29 cd/A at a luminance of 200 cd/m², and an external quantum efficiency (EQE) of 13%, nearly three times the maximum EQE that can be obtained with an equivalent fluorescent device.

Performance of Active-Matrix PHOLED Displays

There have now been many demonstrations of the performance benefits of incorporating PHOLEDs into AMOLED displays in addition to their use in a commercial full-color sub-display. In May 2002, Samsung SDI and UDC presented a joint paper at SID 2002 and demonstrated a 2.2-in. quarter common intermediate format (QCIF) AMOLED containing UDC's red- and green-emitting phosphorescent-device technology. The incorporation of these advanced PHOLED devices reduced display power consumption in the range of 36–52% compared to the same display built with fluorescent OLEDs (Fig. 6). The amount of reduction depends on the trade-off between color gamut and power consumption, as a result of using either RD07 or RD61 PHOLED devices for the red subpixels. The 52% power reduction was for a display with a color gamut equivalent to that of an all-fluorescent display.

More recently, AU Optronics Corp. and UDC demonstrated a full-color display combining an a-Si backplane, red PHOLED subpixels, and green and blue fluorescent-OLED subpixels (Fig. 7). The combination reduced the power consumption by 42% compared to that of an equivalent all-fluorescent device. A 4-in. full-color AMOLED operated at a luminance of 300 cd/m² consumed only 670 mW under video-mode conditions (in which 30% of the pixels were illuminated). An equivalent LCD backlight alone would consume 1.8 W – nearly three times as much.

In conventional fluorescent small-molecule and polymer OLEDs, most of the power is consumed by the red subpixels. High-efficiency red-emitting phosphorescent devices result in a more evenly distributed power consumption among the three primary colors. The lower current requirements of the phosphorescent devices also reduce power losses in the TFT backplane.

New Light from PHOLEDs

Given the rapid advances in OLED technology, interest is growing in the use of these devices as a new source of white light for a range of illumination applications (Fig. 8). OLEDs may offer significant gains in energy efficiency over existing illumination technology while providing other novel performance attributes. In order to compete with conventional incandescent and fluorescent lighting

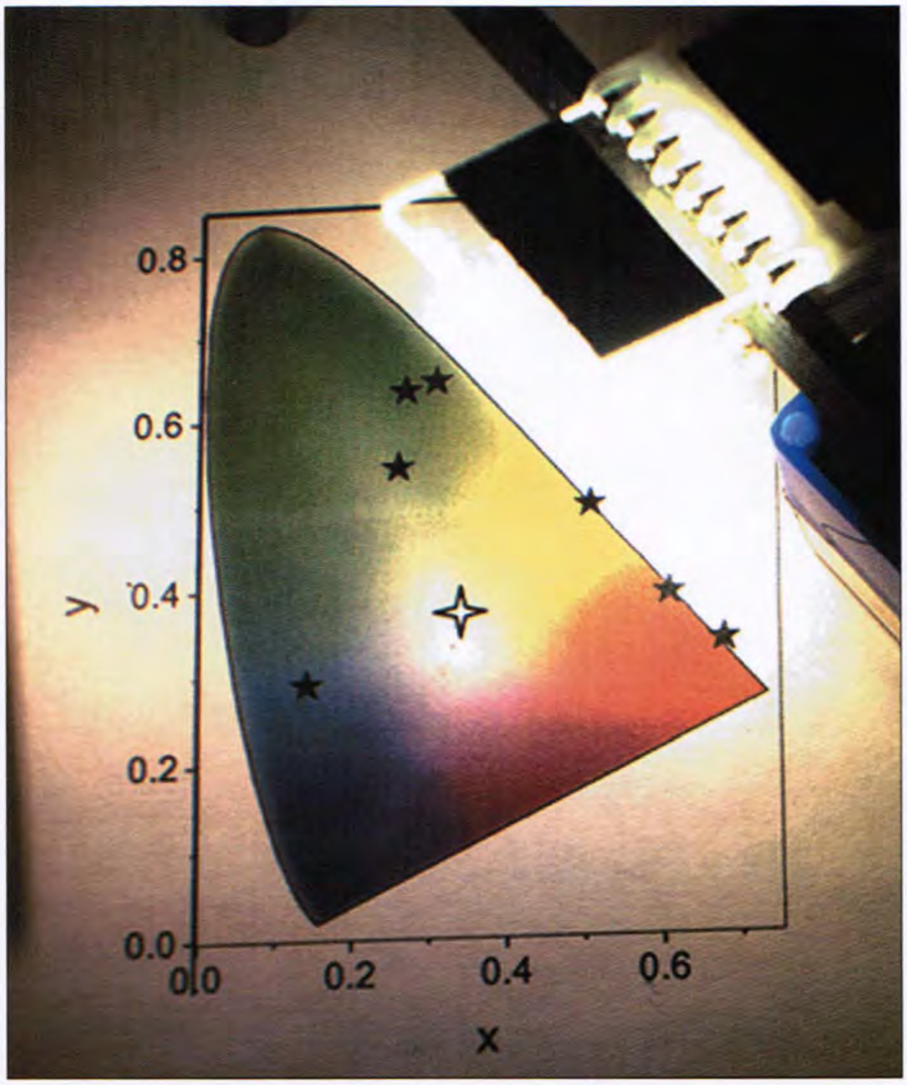

Fig. 8: A white-light PHOLED used as a source of illumination was fabricated in UDC's Pilot Line Facility and may be the forerunner of new lighting devices.

sources by 2010, innovative research and development is required to drive the power efficiencies of OLEDs as white light sources to 100 lm/W. This will require PHOLEDs to operate at close to 100% internal quantum efficiency and to improve outcoupling or extraction efficiency, ensuring that greater than 20–25% of the photons generated by the device are emitted as "useful" light. Research is necessary to optimize the device design in order to reduce electrical losses, so that the drive voltage – multiplied by the electronic charge – is close to the energy of the emitted photons.

A Bright Future

In 2004, many new and exciting OLED-display products will be launched. A key factor in their success will be the incorporation of PHOLEDs, which enable these displays to consume much less power and be more efficient than an equivalent AMLCD. In addition, their very high efficiency may enable the use of lower-cost a-Si backplanes, which would reduce manufacturing costs and provide PHOLED displays with a real competitive advantage. With further improvements in performance and lifetime, PHOLED devices may also become the next generation of solid-state lighting for a wide range of illumination applications. ■

TFTs for OLEDs

AMOLED Backplanes: Amorphous-Silicon *vs.* Polysilicon

Choosing between amorphous-silicon and low-temperature-polysilicon backplanes for active-matrix OLEDs is critical – and not easy.

by Jiin-Jou Lih

ORGANIC light-emitting-diode (OLED) displays have great potential in replacing liquid-crystal displays (LCDs) because of their superior characteristics, including self-emission, video-rate response, wide viewing angle, and a very thin form factor. Active-matrix OLEDs (AMOLEDs) hold the most promise because they can offer higher resolution, larger size, lower power consumption, and longer lifetime.

Thin-film transistors (TFTs) in active-matrix liquid-crystal displays (AMLCDs) function as switches driven by a voltage. On the other hand, a TFT in an AMOLED serves as both a switch and a current supplier because an OLED is a current-driven device. Low-temperature-polysilicon (LTPS) TFTs are frequently used as a backplane for AMOLEDs because LTPS TFTs can provide much higher output current than TFTs made of amorphous silicon (a-Si). LTPS offers higher carrier mobility than a-Si, which helps it deliver sufficient output current for the panel's operation.

However, a-Si has strong appeal to manufacturers because it not only offers lower equipment investment and production costs, but requires fewer process steps than LTPS. A number of research institutes and industrial firms have recently published positive results about a-Si backplanes that may provide alternative roads along the AMOLED's route to commercialization.

With both a-Si and LTPS-TFT facilities available internally, AU Optronics Corp. has been actively investigating both technologies for use as OLED backplanes. In considering them for their suitability as AMOLED backplanes, we have compared the manufacturing and performance aspects of a-Si and LTPS TFTs in terms of their capability, stability, and various driving schemes (Table 1).

TFT Structures

The physical structure of an a-Si TFT differs from that of an LTPS TFT (Fig. 1). Amorphous-silicon backplanes require only five mask process steps, or sometimes even as few as four: gate electrode, a-Si, source–drain electrode, passivation layer, and ITO. The bottom-gate TFT structure is required in order to prevent the leakage of photocurrent. Silicon nitride (SiN_x) is used as a gate dielectric layer because it works well with a-Si. Only *n*-type TFTs are available when using a-Si backplanes.

Table 1: LTPS *vs.* a-Si as Materials for AMOLED TFTs

	LTPS TFT	a-Si TFT
Mobility (cm^2/V-sec)	50–200	0.5–1
Type of TFT	PMOS and NMOS	NMOS
TFT Uniformity	Worse	Better
Numbers of Process Steps	9 or 10 masks	4 or 5 masks
Cost (array only)	High	Low
Cost (module)	Low (Built-in Driver)	High (External Driver)
Equipment Investment	High	Low
Yield	Low	High
Overall Cost	Lower for small panel sizes	Lower for large panel sizes
Current Stability	High	Low
OLED Degradation	Much less sensitive	Much more sensitive

Note. LTPS and a-Si have individual strengths and weaknesses.

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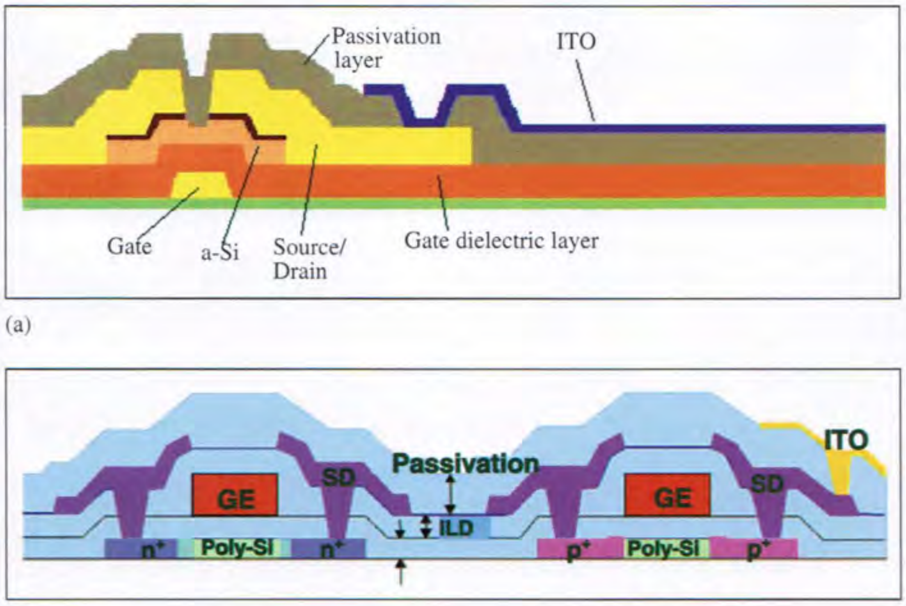

Fig. 1: The structure of the TFTs for an AMOLED is different in (a) a-Si and (b) LTPS backplanes.

On the other hand, nine or ten mask processes are required for LTPS-TFT manufacturing: poly-Si, implant, gate electrode, interlayer dielectric layer, source–drain electrode, passivation layer, and ITO. A top-gate TFT structure is usually employed for higher electron mobility. With both *n*- and *p*-type TFTs available for LTPS, complementary metal-oxide-semiconductor (CMOS) drivers can be integrated directly on the substrate.

Extra equipment is required in the manufacture of LTPS substrates. Excimer-laser annealing (ELA) creates poly-Si crystallization, an ion implanter is needed for impurity implanting, and rapid thermal annealing or a furnace is required for activation. The increased capital investment and larger number of process steps make LTPS-TFT backplanes more costly than a-Si backplanes.

Carrier Mobility

One of the major reasons why an LTPS-TFT backplane is used to drive OLEDs is that it has much higher carrier mobility – usually greater than 100 cm^2/V-sec – than that of an a-Si TFT backplane, which is typically less than 1 cm^2/V-sec. Since an OLED is a current-driven device, a higher current supplied to the OLED results in higher luminance. In the case of an a-Si TFT, which is a device with a larger width-to-length ratio (W/L) and higher operating voltage, it can still provide a current supply sufficient for highly efficient OLED devices, including phosphorescent OLEDs (PHOLEDs).

However, a larger W/L TFT design reduces OLED emission because it produces a lower aperture ratio in the bottom-emitting structure. Because a color pixel consists of a TFT area and an OLED-emitting area, a larger TFT area means that the OLED-emitting area will be smaller. As the resolution gets higher, pixel size gets smaller, but the area of the TFT remains the same; therefore, the OLED-emitting area gets smaller. This could prohibit the a-Si TFT backplane from being used in small OLEDs with very high resolution. The difference in the aperture ratio of a 1.9-in. AMOLED when using a-Si TFTs instead of LTPS TFTs is about 10% (Table 2). As the resolution increases, the aperture ratio will further decrease.

AMOLED Stability

The two major factors which contribute to the lifetime of an AMOLED are the decay of OLED luminance and the decay of TFT current supply. Much progress has already been made in developing new structures and improved OLED materials with slower luminance decay, and major research efforts continue in this area. The ability of TFTs to provide a stable current supply to an OLED is also a crucial factor, with particular challenges for a-Si TFT backplanes.

A basic AMOLED pixel circuit has at least one TFT as a switch and one extra TFT for driving the OLED [Figs. 2(a) and 2(b)]. The switching TFT functions in a manner similar to the one used in an AMLCD to control data signals [Fig. 2(c)]. When a switching TFT is turned on, data signals (voltage) are transferred to the gate of the driving TFT, which then produces a corresponding current to light the OLED. At the same time, the capacitor (C_{st}) is also charged. After the switching TFT is turned off, the charged C_{st} can maintain the original data signal and also permit the driving TFT to continue to supply current to light the OLED. In an AMLCD, the TFT only plays the role of the switch, and the C_{st} maintains the data signal while the switching TFT is turned off, keeping the pixel in the ON state.

OLEDs require a stable output current from the backplane TFTs over time. Because the driving TFT supplies the current to the OLED and is constantly stressed whenever the pixel is on, its stability becomes a critical factor under long-term use. The decrease of output current of the driving TFT is attributed to the characteristic shift after long-term operation [Fig. 3(a)]. The threshold-voltage (V_{th}) shift

Table 2: AMOLED Aperture Ratios in a-Si and LTPS TFTs

	OLED Size (in.)	Resolution	Subpixel Size (μm)	Ratio (%)
a-Si	1.9	128 × RGB × 160	80 × 240	35
LTPS	1.9	128 × RGB × 160	80 × 240	45

Note. Because of the larger TFT devices, an a-Si backplane has a lower aperture ratio than an LTPS backplane.

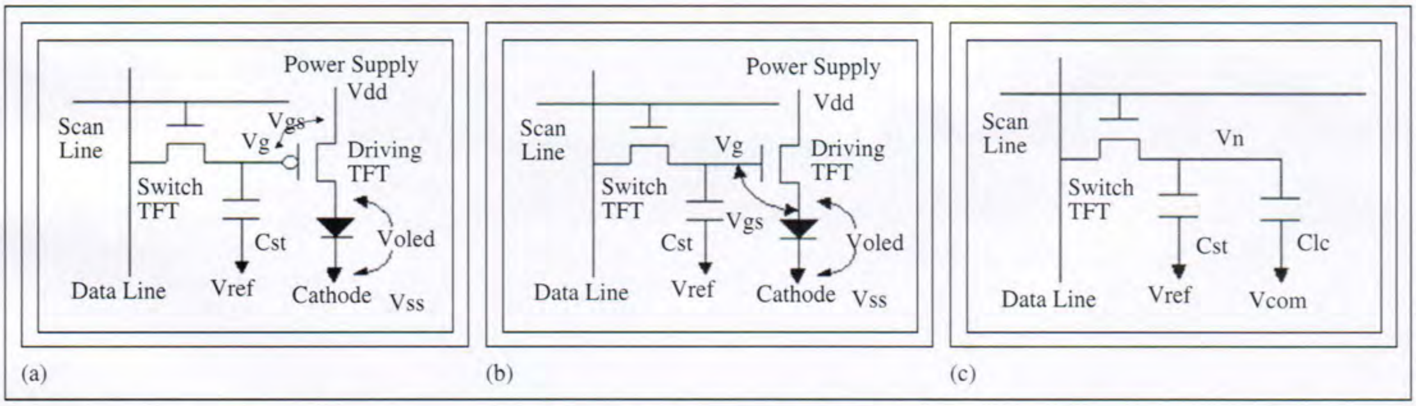

Fig. 2: The typical pixel circuits for (a) an LTPS-TFT AMOLED and (b) an a-Si TFT AMOLED require a driving TFT not found in a typical (c) AMLCD pixel circuit.

of a-Si TFTs can be as large as 2 V, and the current output is decreased by as much as 25% of its initial output when driven at 6 V – an effect that is probably the result of charge trapping. After a certain period of TFT operation, the carrier is trapped at the interface of the a-Si and dielectric layers, which increases V_{th}. As a result, a higher V_{gs} is required to maintain adequate output current.

LTPS TFTs, on the other hand, are quite stable over time. In testing, an output-current drop was not observed even after a few thousand hours of operation for LTPS TFTs, while the output current significantly decreased in the case of a-Si TFTs [Fig. 3(b)].

Both *n*- and *p*-type TFTs can be made with LTPS. A *p*-type TFT can be used as the driving TFT, so the OLED can be positioned at the drain end of the driving TFT. On the other hand, a-Si backplanes can only provide *n*-type TFTs, so the OLED can only be placed at the source end of the driving TFT.

The operating voltage of an OLED device often increases with time. In order to maintain a stable current supply, a *p*-type TFT is used as the driving TFT in LTPS backplanes. The V_{gs} is determined by V_{data} and V_{dd}, and would not be affected by the OLED's voltage drop.

On the other hand, only *n*-type TFTs are available in a-Si backplanes. The V_{gs} is determined by V_{data} and (V_{ss}-V_{OLED}). As V_{OLED} increases with time, V_{gs} is reduced. The output current from the *n*-type driving TFT is decreased. Two approaches can be used to alleviate this problem:

1. A stable OLED device with a very small V_{OLED} increase can minimize the effect.
2. A compensation pixel circuit can reduce the decay of the output current. For example, three TFTs are needed for each pixel in the circuit described by Kanicki. There was significant reduction of output current – from 100 to 28%. But the aperture ratio is further reduced by adding

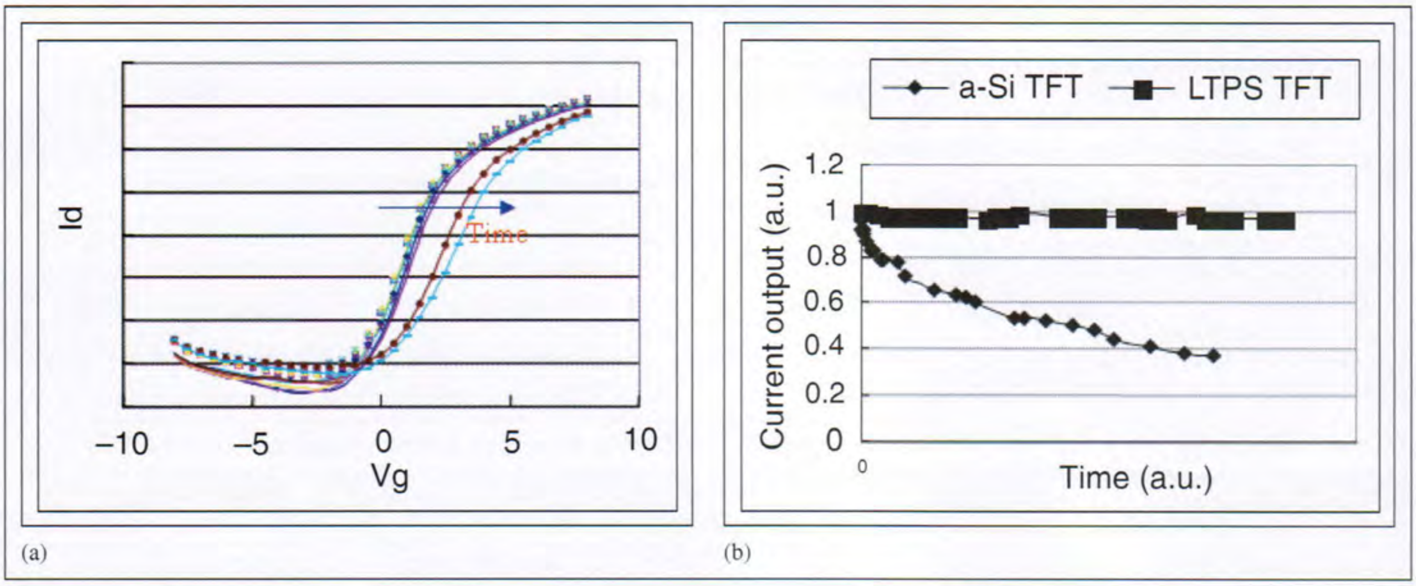

Fig. 3: (a) Over long-term operation, the current of an a-Si TFT shows a characteristic shift. (b) The output current decays much more rapidly in an a-Si TFT than in an LTPS TFT.

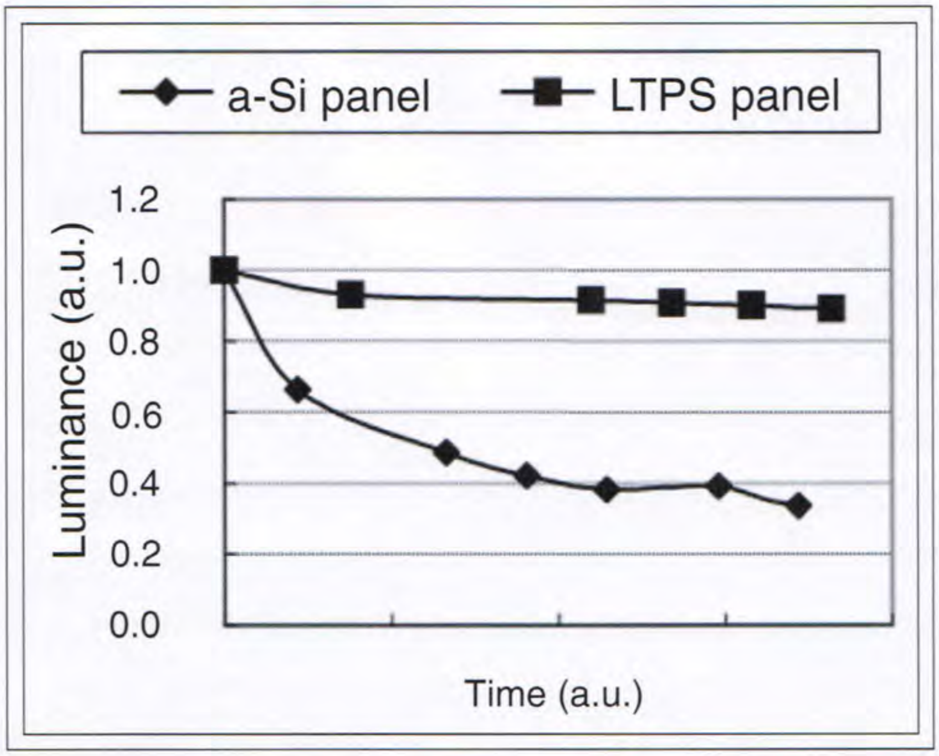

Fig. 4: *In an LTPS-TFT AMOLED, the luminance is much more stable than in an a-Si TFT AMOLED.*

more a-Si TFTs to each pixel, which limits the application of the compensation-pixel-circuit design.

Luminance decay is much lower in an AMOLED fabricated on an LTPS-TFT backplane than in one using an a-Si backplane (Fig. 4). The luminance degrades rapidly in the a-Si AMOLED, but the LTPS AMOLED maintains a constant luminance, with only 10% decay over the same period. The LTPS current decay is, in fact, responsible for less than 1% of this loss in luminance.

The efforts to find a solution to the instability of a-Si include improving the interface by reducing the dielectric-layer roughness and plasma treatment. In addition, the "Super Amorphous Silicon" technology reported by Tsujimura and colleagues extends the a-Si output current. Nonetheless, the characteristics of a-Si still shift with time.

Display Performance

Amorphous-silicon backplanes have one performance advantage over LTPS backplanes. In the manufacture of LTPS TFTs, the poly-Si is crystallized by ELA. Due to the difficulty in achieving uniform crystallization, the uniformity of the LTPS-TFT output current is affected because of differences in threshold voltage, carrier mobility, and subthreshold swing due to the different degrees of crystallization in various areas of the backplane. The result is a lack of brightness uniformity in the final display. In the case of an a-Si AMOLED, the a-Si layer is deposited by chemical-vapor deposition (CVD), eliminating the necessity for extra process steps. The brightness uniformity throughout the entire display is very good. In terms of the brightness-uniformity requirements of large AMOLEDs, they are better satisfied by a-Si TFTs than by LTPS TFTs.

Summary

Both LTPS-TFT and a-Si TFT backplanes have their advantages and disadvantages in AMOLED design. Amorphous-silicon technology has the advantage of being less expensive to produce and has demonstrated the ability to support AMOLEDs. It is more uniform and requires fewer process steps than LTPS technology. On the other hand, LTPS has advantages in terms of device-structure design, higher aperture ratio, carrier mobility, and stability over time.

Research continues to improve both technologies, especially in seeking methods to eliminate the shortcomings of the less-expensive a-Si technology. Whether or not the improvements can be made without compromising the cost and production advantages remains to be seen. One fact is clear, however. If AMOLEDs are to achieve their full potential and compete effectively with the incumbent AMLCD technology, solving the affordability and reliability problems of TFT backplanes is an essential step. ■

Long-Term Value Growth of Display Technologies

The market value of newer display technologies is growing faster than the CRT's market value did, and that bodes well for the industry's future.

by Kimberly Allen

IN THE RUSH TO GENERATE value each quarter, it is easy to ignore considerations of truly long-term growth. Few in the display industry doubt that thin-film-transistor liquid-crystal displays (TFT-LCDs) and organic light-emitting diodes (OLEDs) are currently experiencing high growth, while cathode-ray tubes (CRTs) have settled firmly into maturity. But how does the growth of these newer technologies compare to that of the CRT in its early years?

One way to address this question is to compare the market value of several display technologies as a function of the year since volume sales were achieved. The CRT first had volume sales in 1946, the LCD in 1970, the TFT-LCD in 1983, and the OLED in 1998. Stanford Resources has data on these products beginning in 1963, 1972, 1991, and 1998, respectively (the latter three completely from within the company's own files). What patterns can be found by analyzing these data?

Dealing with Inflation

First, some comments on long-term valuations need to be made. It is very difficult to compare market values over many decades for two reasons, one fairly straightforward and one less so.

The simpler issue is that inflation of the dollar distorts data over decade-long time scales. Forecasts are usually given in current dollars, *i.e.*, in dollars for the year of the data, or perhaps for the first year of a several-year forecast. The way to correct for this effect is to rescale the data to constant dollars of some year.

A subset of this issue is how to inflate the dollar over time. The consumer price index (CPI) is often used for commercial goods, but it is not appropriate for technologies. A better method may be to use the gross domestic product (GDP) implicit price deflator. Data for both of these methods can be found on United States Government Web sites.

The more difficult issue is that a simple economic deflator cannot account for changes in the technology's quality over time. A CRT in 1950 was a much cruder device than that found on the shelves of today's electronics superstores. How can an analysis capture this change in quality that occurs over decades in the market?

In this analysis, we have addressed the issue of basic inflation by using the GDP deflator, with all market values scaled to constant 1996 dollars. The issue of quality

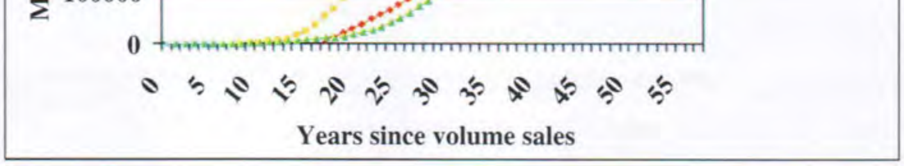

Fig. 1: *Worldwide electronic-display value is shown as a function of time in the market, in millions of constant 1996 dollars. (Source: iSuppli/Stanford Resources)*

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over time is not addressed because of its complexity.

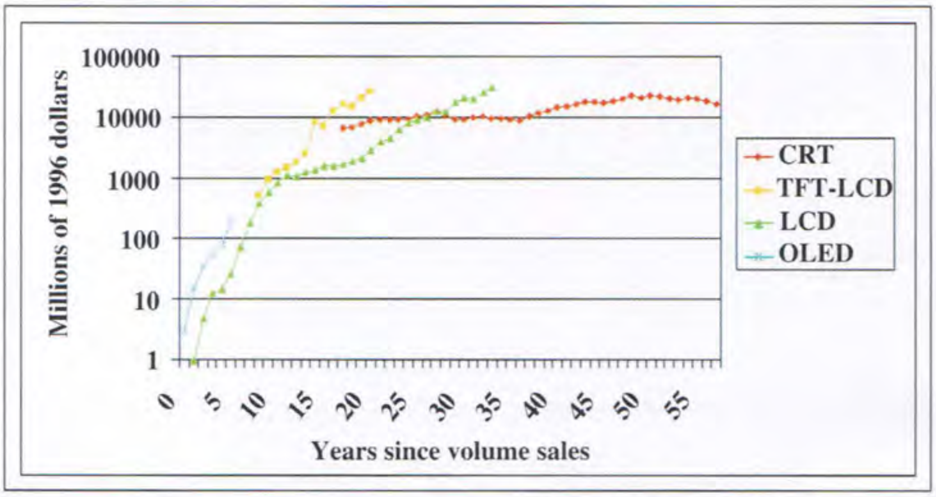

Fig. 2: Cumulative worldwide market value is shown by display technology, in millions of constant 1996 dollars. (Source: iSuppli/Stanford Resources)

Total Market Value

A plot of the market value of the CRTs, LCDs, TFT-LCDs, and OLED displays (in constant 1996 dollars) as a function of time since the first volume sales shows, as we would expect, that the CRT's curve has flattened out and is indeed beginning to decline (Fig. 1). Although we have no data for the early years of the CRT curve, it appears that compared to the CRT, the LCD gained value somewhat more slowly. For example, by the LCD's 20th year in the marketplace, it was bringing in significantly less real revenue than the CRT did in its 20th year. This is because the CRT quickly entered a large-volume consumer market: television.

Beyond 25 years in the marketplace, LCDs have pushed above the CRT curve. This is primarily due to the explosion of the notebook-computer market in the early 1990s, which is responsible for the change of slope in the LCD curve around its 20th year. The high growth of flat-panel desktop monitors is pushing the LCD curve even farther above the CRT at this time.

Separating out the TFT-LCD from the total LCD curve supports this point. Ten years after entering the market, TFT-LCDs were bringing in more revenue than LCDs as a whole did after their first ten years. This is the same notebook-and-monitor phenomenon.

The real star is the OLED display. Within a few short years of first shipping products, OLED manufacturers are bringing in many times the revenue enjoyed by LCD manufacturers in their early years. Although nearly all current OLED products contain passive-matrix displays, the real revenue rivals that of the TFT-LCD. According to iSuppli/Stanford Resources' most recent OLED forecast, this growth curve will continue into the future.

Why do the newer display technologies – TFT-LCDs and OLEDs – ascend the market-value curve more quickly than the older ones did? Figure 1 alone cannot tell the whole story, but some speculations can be made. One possibility is simply that newer technologies are benefiting from the established infrastructure of the semiconductor and early LCD industries. CRT and LCD players had to build their industries essentially from scratch. But with the explosion of electronics in the '70s and '80s, and the knowledge gained from passive-LCD manufacturing, newer display technologies could integrate into the system much more readily. This helped not only manufacturing, but also distribution, marketing, and sales. It is possible that these efficiencies allowed the creation of value earlier.

A further possibility is that the market has come to accept higher-value displays as these items have become more important in daily life. Displays are now used in many more products than they were even ten years ago. Consumers are getting used to seeing attractive, colorful flat panels everywhere. It is not only the unit shipments of OLEDs that have driven the early value so high; it is also the price. The market is buying more displays, at a higher price, earlier in the technology's life cycle than ever before.

Cumulative Market Value

Another way to look at the data is to add up the cumulative market value (Fig. 2). Again, the results are adjusted for inflation by scaling to constant 1996 dollars. The vertical scale is in millions of dollars, so the CRT has topped \$550 billion of revenue over its lifetime. The LCD is just above \$200 billion, with a bit more than half of that generated by TFT-LCDs thus far. The OLED values are too small at this point to appear clearly on the graph. Since the CRT data start in year 17 and the TFT-LCD data start in year 8, both of those curves should be shifted vertically by the value of the shipments to that point. It is likely to be a small shift, however (less than \$10–15 billion) and the shapes of the curves would not be affected.

The cumulative market value is one view of the famous "S-curve" that is supposed to describe a technology's birth, ascendance, and maturity. Figure 2 shows that this curve has not fully played out for the CRT yet, but we can see that the inflection point was reached around year 50–55. The S-curve inflects when revenue begins to decline and becomes horizontal when there is no more revenue, *i.e.*, when the technology exits the marketplace.

The LCD's somewhat slower rise compared to that of the CRT is reflected in its lower cumulative value until about its 32nd year in the marketplace. The TFT-LCD portion of the LCD's cumulative value has risen more quickly. The steeper slope of the LCD indicates that this technology is likely to ultimately bring in more revenue over its lifetime than the CRT will.

These results add up to an optimistic outlook for new display technologies. The trend suggested in Fig. 1 is toward products that bring in revenue earlier, which could feed a cycle of greater interest and investment in display technologies. As indicted in Fig. 2, newer display technologies may ultimately create more value than older ones. ■

LCD design

Improving the Moving-Image Quality of LCDs by Using Impulse Driving

New cell designs, LC materials, and overdrive technology have improved the response time of LCDs substantially, but more work is needed to minimize the blurring of moving images.

by Jun-ichi Ohwada

LARGE LCD TVs have recently become popular consumer products. Their image quality has been improved mainly by the use of wide-viewing-angle LCD modes, such as in-plane switching (IPS) or vertical alignment (VA). Designers have successfully provided products with high brightness, high contrast ratio, and wide viewing angle. But the moving-image quality of LCD TVs is not as good as that of CRT TVs. When moving images are displayed on large LCD TVs, the human visual system detects blurring. The blurring is produced not only by the poor response-time characteristics of the LCD itself, but also by the hold mode of the LCD and the manner in which it interacts with the human visual system. An approach called the "impulse-driving method," developed at Hitachi Displays, counteracts the blurring. Its effectiveness has been confirmed by human testing, and LCD panels incorporating this technology are now available in commercial TV sets.

Blurring Countermeasures

The two primary factors responsible for inadequate moving-image quality in LCDs are the response-time characteristics of the LCD itself and the blurring caused by the hold mode.

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To put it as bluntly as possible, when a moving image is displayed on LCD panels, blurring occurs. If that image is a black box moving horizontally across the screen, blurring occurs at the leading and trailing edges of the box (Fig. 1, top). If cinematic imagery containing rapid motion is displayed on an LCD, blurring occurs over the entire image (Fig. 1, bottom).

We can make the following general statements about the blurring of moving images on displays:

- Blurring is observed only minimally on CRTs.
- Blurring becomes worse as images move faster and as screen size becomes larger.
- Blurring can be reduced by using fast-response LCDs, but it is still visible. In viewing displays that have hold modes, such as LCDs and PDPs, the human visual system detects blurring even if the response characteristics of the LCD are fast enough, so blurring should not be expected on the basis of response time alone.

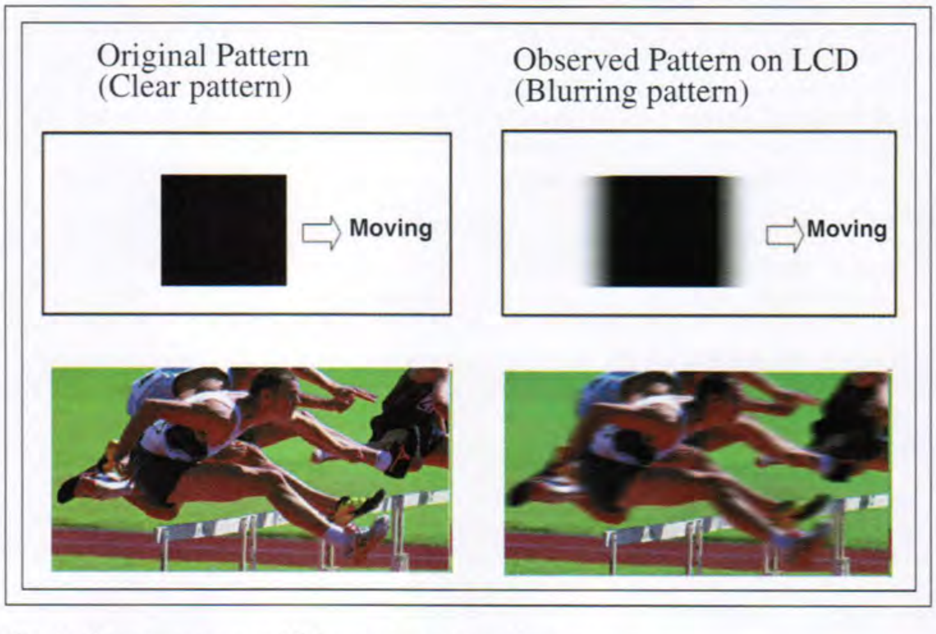

Fig. 1: *When images on an LCD are set in motion, blurring occurs.*

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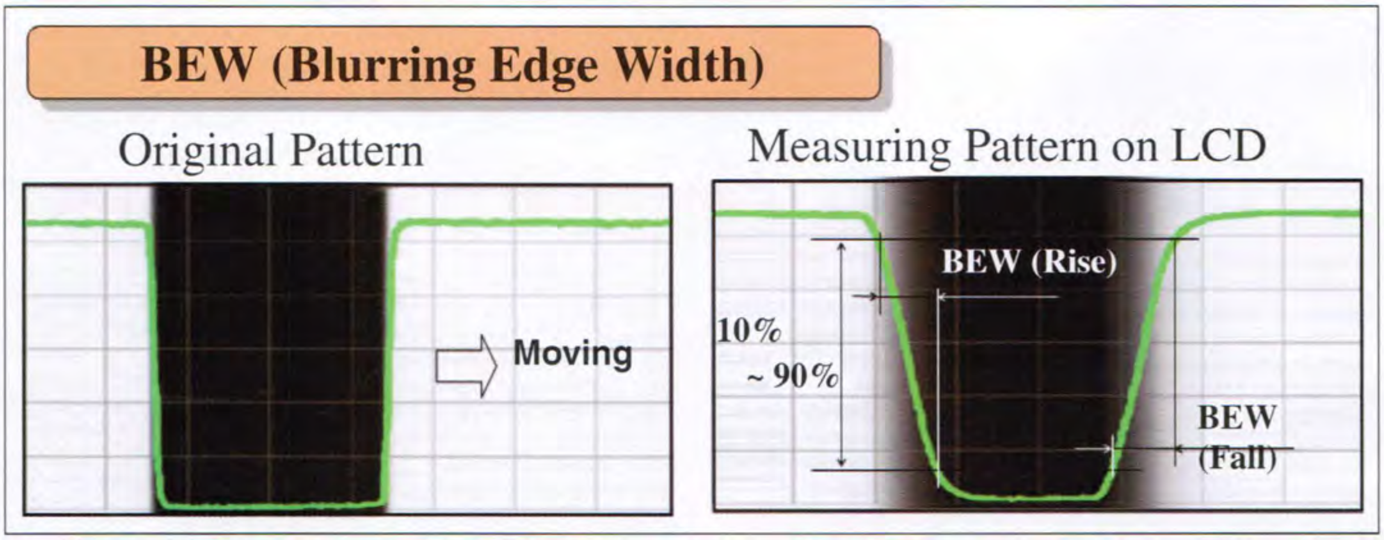

Fig. 2: *A good parameter for evaluating the blurring of moving images is the blurring-edge width (BEW), which is the width of the gray areas in percentage, from 10 to 90%, of the luminance levels.*

A set of evaluation parameters for blurring has been proposed, one of which is the blurring-edge width (BEW). As can be seen in Fig. 1, when a black box moves across a white LCD screen, gray areas are observed in the vicinity of the black box. The BEW is defined as the width of the gray areas in percentage, from 10 to 90%, of the luminance levels (Fig. 2).

BEW is dependent upon the LCD response time, but frame frequency (f_v) is also an important parameter (Fig. 3). Each dot in the figure represents a BEW value measured on an LCD screen that has several different response-time characteristics. Each line represents BEW simulation values. As the value becomes smaller, blurring becomes less noticeable. When the value is smaller than 0.4 (in this figure), blurring is hardly noticed by the viewer. When the value is between 0.4 and 0.7, blurring is tolerable from a practical standpoint.

When the response time of an LCD is more than 10 msec, the value is proportional to the response time. But when the response time is less than 10 msec, the BEW does not decrease proportionally with response time. In this regime, the BEW value is not determined by the response characteristics but by the frame frequency. When the frame frequency increases, the BEW becomes smaller. At a 60-Hz frame frequency, the BEW can not be reduced below the tolerable limit of blurring even if very fast response times are used.

Unfortunately, blurring is an inherent characteristic of hold-mode displays such as LCDs, PDPs, and OLEDs, but there is a basic strategy for the reduction of blurring (Fig. 4). The first countermeasure is to improve the response-time characteristics of the LCD itself. New LC materials with lower viscosity or a new driving method such as overdriving

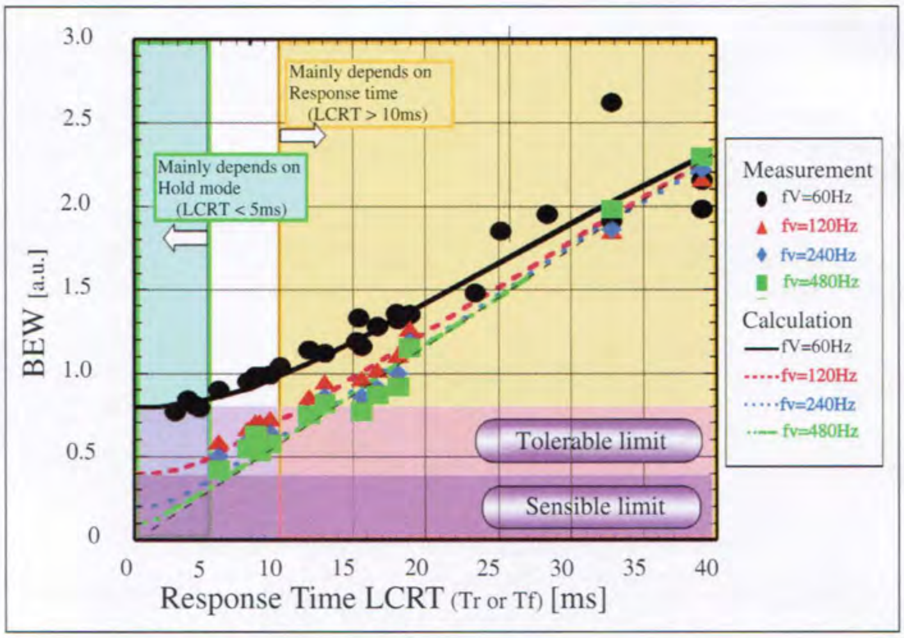

Fig. 3: *BEW depends on the LCD response time, but frame frequency (f_v) is an important parameter as well. Each dot in the figure represents a value of BEW measured on actual LCD screens that have several response characteristics. Each line represents values of BEW calculated by simulation.*

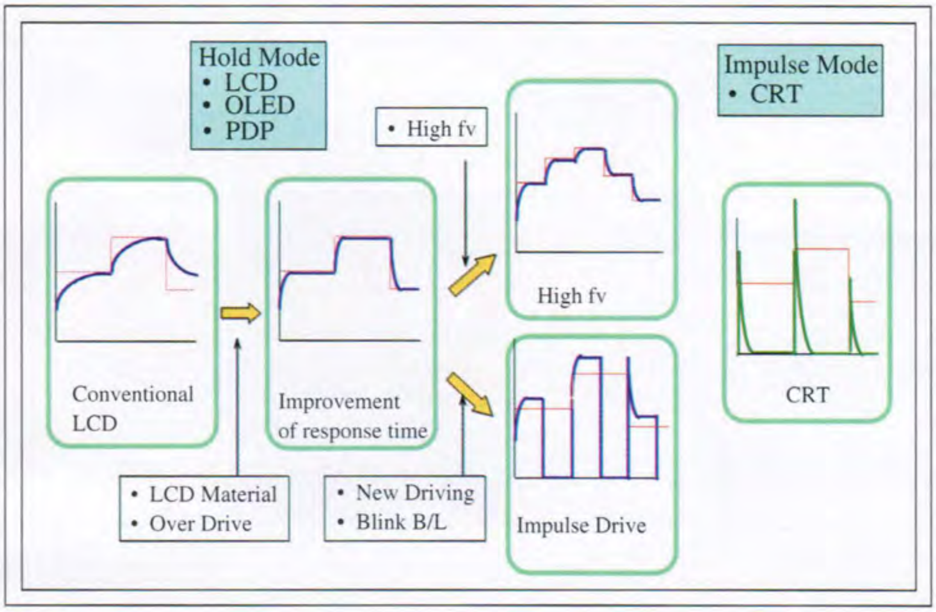

***Fig. 4:** The strategy for improving the moving-image quality of LCD TV is not limited to response-time compensation.*

can be effective. A second countermeasure employs a high-frequency frame-rate drive, or impulse driving, to reduce blurring.

Two main impulse-driving methods which have been proposed are black-image-data insertion and the blinking backlight (Fig. 5). The blinking-backlight method of blurring reduction is implemented by turning off the backlight's cold-cathode fluorescent lamps (CCFLs) periodically.

In the black-data-insertion method, the black-image data is inserted sequentially after the real-image data in each frame. As the period in which black data is inserted becomes longer, the blurring becomes less noticeable but the image becomes darker. In the case of a 20-in.-diagonal wide-XGA LCD-TV panel, the trade-off between these two characteristics is optimized by setting the black-data period at half the total frame period (Fig. 6).

Evaluation and Testing

Testing to evaluate black-image-data insertion, with and without a type of overdrive called Dynamic Contrast Control (DCC), was carried out with 21 persons selected from the general population. The use of DCC overdrive reduced the gray-to-gray response time to 20 msec (maximum) for the IPS-mode LCD screens that were used. The subjects were asked to look at one of two moving test images on a CRT and then on one of four different 20-in. WVGA LCD panels mounted in Hitachi WOOO LCD-TV sets.

The four panels had (1) neither DCC overdrive nor black-data insertion, (2) only DCC overdrive, (3) only black-data insertion, or (4) both DCC overdrive and black-data insertion. The testing was carried out in a room illuminated by 440 lux horizontally and 120 lux vertically. The subjects were then asked to evaluate their impression of the blurring on each LCD screen on a scale from 1 (very annoying) to 5 (imperceptible).

Applying the DCC-overdrive method improved the average blurring rating by half a grade, while black-image-data insertion improved it by a 0.7 grade. The application of both methods improved the rating by about one grade. In this evaluation, black-image-data insertion had a greater effect than DCC overdrive.

Conclusion

Blurring is caused not only by the response-time characteristics of the LCD itself but also

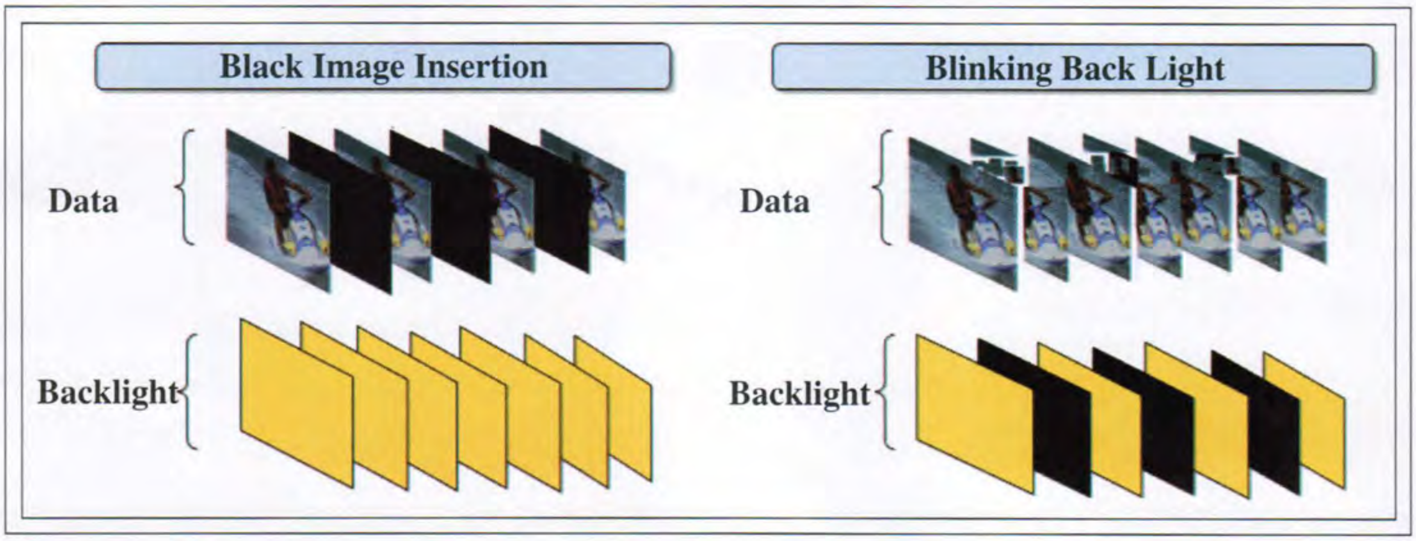

***Fig. 5:** Impulse driving can be implemented by either black-image-data insertion or a blinking backlight.*

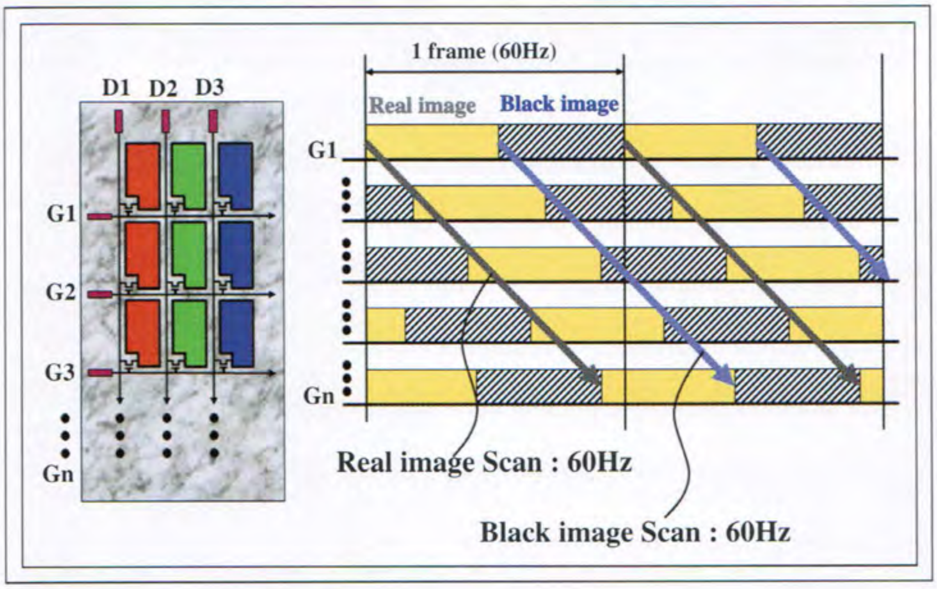

Fig. 6: In a 20-in.-diagonal wide-XGA LCD TV, a balance between blurring reduction and loss of luminance may be achieved by setting the black-data period at half the total frame period.

by the hold mode of LCDs and its interaction with the human visual system. Impulse driving significantly reduces blurring, and it is even more effective in combination with DCC overdrive for response-time compensation. The type of impulse driving known as black-image-data insertion is effective in reducing blurring, but at the expense of luminance. ■

conference report

Large-Screen TV Fuels Record Attendance at CES

The world's largest PDP TV and the world's thinnest rear-projection TV drew crowds at the Consumer Electronics Show, but nothing excited the industry professionals more than rapidly increasing digital-TV sales.

by Ken Werner

A RECORD 129,000 industry professionals attended the Consumer Electronics Show, held January 8–11 in Las Vegas, Nevada. More than 2400 exhibiting companies occupied 1.38 million square feet of net floor space – equivalent to 48 football fields – at the Las Vegas Convention Center, the Las Vegas Hilton, the Alexis Park Resort, and the Riviera Convention Center. On January 8, there wasn't a vacant hotel room to be found.

The enthusiasm was fueled by a resurgent consumer-electronics market. The Consumer Electronics Association (CEA), the trade association that produces CES, projected that factory sales and imports of consumer electronics to the U.S. will be $101 billion in 2004, up 4.8% from 2003. Even better, CEA projects that sales in 2005 will be over $106 billion.

Digital TV sets and displays are an important part of this total. Projected sales of direct-view and projection digital TVs in 2004 are $8.02 billion, up from $6.15 billion in 2003. Sales to U.S. dealers of LCD TVs (both analog and digital) are projected to reach over $1 billion in 2004, up from $651 million in 2003. (The associated unit sales are 1.7 million in 2004; 1.1 million in 2003). Sales of PDP TVs are projected to increase from an estimated $1.5 billion in 2003 to a projected $2.2 billion in 2004 (figures by permission of CEA).

Gary Feather, ***Sharp***'s Director of Digital Audio Video Systems, told *Information Display* that his company's Gen 6 plant at Kameyama, Japan, which went into full production in January, is running at full capacity to fill orders for LCD-TV panels. The line's 1800 × 1500-mm motherglass accommodates eight 32-in. panels or three 45-in. panels. All of the large Sharp displays shown at CES were made on the Kameyama line, Feather said. Sharp projects that it will sell 2 million LCD-TV sets outside Japan in 2004, 1.2 million of which will be in the U.S. In addition, Feather estimated that Sharp will sell slightly less than 2 million sets inside Japan.

"We are truly experiencing something we have never seen before," said Feather. "Busi-

Ken Werner

Fig. 1: At CES, Sharp showed a wide range of AQUOS LCD HDTV models, including a newly introduced 45-in. 1920 × 1080-pixel LCD TV, the company's first commercial offering above 37 in.

Ken Werner *is the editor of* Information Display *magazine.*

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ness is growing at a rate never dreamed of, and this has major implications for funding of infrastructure, R&D, and product development." Sharp was showing new 26-, 32-, and 37-in. AQUOS HDTV models; the 26- and 32-in. models are new sizes for the company (Fig. 1). In addition, there was a newly introduced 45-in. 1920 × 1080-pixel LCD TV, the company's first commercial offering above 37 in. The 45-in. will be in production this summer, Feather said.

Bruce Berkoff of ***LG.Philips LCD*** said, "This is the year of the 26-in.," meaning that he sees 26-in. LCD TVs as being in the sweet spot of price *vs.* size and experiencing large sales. In part, this is due to 26-in. panels being a particularly good fit for LG.Philips LCD's Gen 6 manufacturing lines. When the Gen 7 line ramps up next year, larger sizes will gain larger shares of the company's consumer-product mix. Now, LG.Philips LCD's 42-in. is selling primarily for advertising applications.

For notebooks, LG.Philips LCD has 15.4- and 17.1-in. TFT-LCD modules with a new pixel format of 1680 × 1050, which is called SXGA+. There is substantial demand for this format in these sizes from notebook manufacturers, Berkoff said. The same pixel format is available in a 20-in.-monitor module.

LCD and PDP TVs were being shown by an impressive number of CES exhibitors who are not household names. ***Apex***, the company that brought the low-cost DVD player to the U.S., was showing 27- and 30-in. 720-line wide LCD TVs (the 30-in. actually had 768 lines). ***Norcent*** had a large booth in the South Hall with a wide range of PDP and LCD TVs as well as LCD monitors. The company announced it had added Ingram Micro to its distributors.

Although Apex and Norcent sell products under their own names, many manufacturers – such as ***erae electronics*** (Seoul), ***Viewell*** (Seoul), and ***Monivision*** (Tao Yuan, Taiwan) – were vying for OEM and private-label business. ***The Hong Kong Trade Development Council*** (Los Angeles) had a large pavilion to make it easier for smaller Hong Kong companies to exhibit at CES (Fig. 2).

Ken Werner

Fig. 2: *The Hong Kong pavilion made it easier for smaller Hong Kong companies to exhibit at CES.*

Very Big

Large screens were everywhere at CES. ***Samsung*** recaptured the "world's largest" record for PDPs by introducing an 80-in. PDP prototype, and retained the title for TFT-LCDs with its 57-in. prototype, which had been shown before in Asia. LG.Philips LCD's 55-in. module, which was briefly the world's largest last autumn, was on display in its maker's suite. Samsung's 80-in. PDP TV has 1920 × 1080 pixels, a 2000:1 contrast ratio (CR), and a luminance of 1000 nits; along with one ATSC/QAM tuner and one NTSC tuner, and HDMI and DVI digital interfaces (Fig. 3).

LG Electronics said it was in full production with its slightly smaller 76-in. PDP TV, which will be on sale later this year when inventory builds up and distribution channels are filled. In their booth was a unit with full-HD 1920 × 1080 pixels, 800 nits of luminance, and a 1000:1 CR. A nearby 71-in. HD unit with 900 nits and a 1500:1 CR exhibited noticeably more contrast than the 80-in. version

Some of the PDP TVs in ***Pioneer***'s booth were based on the company's new fourth-generation glass, said Jeff Dickson, Marketing Manager for Displays in Pioneer's Home Entertainment Division. The fourth-generation displays produce a luminance of 1000–1100 nits. Ten-bit-per-channel color generates more than one billion colors for visibly better detail in dark areas. (Less than a month after CES, Pioneer announced it was acquiring NEC's PDP business.)

Daewoo Electronics America's lead press release was entitled "Its Financial Turnaround Complete, Daewoo Electronics Is Poised to Become a Leader in Digital Display." Daewoo was celebrating its return with its largest CES booth ever, highly styled products, and PDP-TV prototypes with motorized height adjustment. But among the company's most interesting assets is its New Jersey based U.S. Design Director, Guan-Woo Yoon.

Yoon said that Daewoo is focusing on PDPs, and selling a lot of them, and that the company's approach for the next step is high-style design – the product as furniture. "Good materials give a sense of beauty, integrity, and strength." But Daewoo does not think it makes sense for it to compete directly with much larger companies in developing new display technology, especially when the existing performance level is so high.

"New technology is expensive," said Yoon. "We are trying to combine existing technologies to provide extra consumer benefits at modest cost." Many companies have good display technology, but technology must be coupled with good design "to touch the human heart."

Yoon said that Daewoo is proud of its wireless technology. In the booth, the company was transmitting HD video to two large-screen displays and XGA imagery to a Viewsonic tablet PC.

A novel feature of the large ***Philips Electronics*** booth, aside from the huge globe of FPDs used to illustrate the concept of a "connected planet," was the company's "ambilight" display – a wall-mounted 42-in. LCD TV with indirect lighting behind the left and right edges (Fig. 4). The color of the light could be adjusted manually or controlled by the program material, a company representative said. Many editors and analysts were more inclined to greet this innovation with chuckles rather than awe. But at a CES where major commitments were made to make not only products but the entire consumer-electronics buying experience more appealing to women, perhaps the levity was premature.

There was nothing but respect for Philips's Cineos rear-projection displays, which use a single, relatively large liquid-crystal–on–silicon (LCoS) microdisplay and a scrolling-color-field design. Versions with 44-in. (MSRP $3299) and 55-in. (MSRP $3999) screens were scheduled for Q2 '04 availability. A 62-in. version (MSRP $4799) was scheduled for June.

Philips was also showing its Steamium™ wireless TV, which uses an 802.11g link to deliver 1024 × 768 imagery.

Konka, a leading Chinese TV manufacturer based in Shenzhen, showed a 46-in. PDP TV and a range of CRT TVs, including a 36-in. HD flat-screen model.

Ken Werner

Fig. 3: Samsung secured the "world's largest PDP" title by introducing this 80-in. PDP prototype at CES.

New and Interesting

Texas Instruments' Mixed Signal Video Group (Dallas, Texas), which is not to be confused with the DLP group, was discussing a pair of recently introduced all-format video decoders. The high-performance TPV5146 is used in products such as LCD TVs and TV/monitors, PDP TVs, PC video cards, and DVD-R decks, where multiple inputs, multiple analog-to-digital converters, 10-bit output, and a five-line 2-D comb filter are needed, said Ron Richter, Marketing Branch Manager for TI Digital Video Products. Richter broke the marketer's rule about not discussing the next generation of a recently released product by saying that the next generation of the 5140 series will incorporate a 3-D comb filter.

The TVP5150 is the 5146's low-power low-cost small-package cousin, intended for cellular telephones and PDA TVs, digital camcorders, USB-powered video, PC laptop TVs, and second TV tuners for PIP. It comes in a 32-pin TQFP package and consumes only 120 mW.

Fergason Patent Properties (Menlo Park, California), which licenses some of the patents of James L. Fergason – an inventor of the twisted-nematic field-effect LCD – was demonstrating its System Synchronized Brightness Control (SSBC) in a suite during CES and touting its recently completed licensing agreement with LG.Philips LCD. The system improves the detail in dark scenes by reducing the percentage of the frame time that the backlight is on and simultaneously recalibrating the available gray levels so that all the levels can be used. A license was sold to Matsushita in early 2002, and commercial Matsushita video monitors were being used for the demonstration.

HyTek Manufacturing Co. (Yorkville, Illinois) showed its award-winning TekPanel™ 370 all-in-one multimedia computer, which integrates a generous selection of PC and multimedia components, including a 125-channel tuner in a 37-in. TFT-LCD monitor. A wireless keyboard and mouse are part of the package.

As already indicated, several TV makers – including Sharp, Philips, and Daewoo – were showing medium-sized wireless LCD-TV sets using WiFi (IEEE 802.11) technology. Those (like Sharp) that used 802.11b were limited to VGA resolution, while those using 802.11a or 802.11g were able to go to XGA. Wireless, and, to a lesser extent, one-wire systems for

HD images and large screens were also a hot topic. After all, no one wants to see a bunch of unsightly wires hanging down from a big-screen wall-mounted TV.

NXT (London, U.K.) was showing its speaker-on-panel SoundVu™ technology, winner of the SID/*Information Display* 2003 Display Material or Component of the Year Silver Award, on the show floor and in a suite. It was much easier to hear in the suite. The sound quality in various medium- and large-screen applications was very impressive. The total harmonic distortion is comparable to that found in traditional speaker technology, said SoundVu Business Sector Head Geoff Boyd, but frequencies below 120 Hz are intentionally cut off because below 100 Hz it is possible to see the effects of the vibrating panel. In many TV and monitor applications, a subwoofer is used to supply the low frequencies.

Where the SoundVu technology went from impressive to startling was in a newly introduced NEC notebook PC. We are simply not used to hearing high-quality sound emanating from a notebook. This is a feature that can sway the buying decisions of certain categories of users.

IBIZ (Phoenix, Arizona) announced that its laser-generated virtual keyboard had begun shipping. A small case sits on a tabletop or other flat surface and projects the image of a full-sized keyboard on the surface. When the user's fingers touch (or come close to) the image of a key, it is actuated. The battery-powered device costs $99 (MSRP) and connects to Palm, Pocket PC, and Windows™-based devices. A $129 Bluetooth version was scheduled to be available in June. Limitations? The device requires a flat surface and will work in bright interior illumination, but not in sunlight.

JJ Communications (Englewood, New Jersey) showed its new $299 (MSRP) MagniCam, a VGA digital camera with variable 1–150× optical magnification in a housing that looks like that of an electric toothbrush. It was originally developed for home medical applications, but the makers now realize there could also be application among hobbyists such as stamp and coin collectors, document specialists, craftsmen, and artists.

Ken Werner

Fig. 4: Philips Electronics seemed enthusiastic about its "ambilight" display – a wall-mounted 42-in. LCD TV with indirect lighting behind the left and right edges. (The enthusiasm was not universally shared by analysts.)

Microdisplays

Makers of microdisplay imagers, light engines, and finished television sets were aggressively showing their wares at CES. Purveyors of microdisplay-based rear-projection TVs, in particular, see an opportunity to compete with direct-view large-screen TVs. The potential opportunity is based on price and perhaps, in some cases, moving-image quality.

Texas Instruments (Plano, Texas) introduced its new xHD3 and HD3 chips for Digital Micromirror Device™ (DMD™) microdisplay imagers at CES. The xHD3 brings 1080-line-progressive high-definition images to TI Digital Light Processing™ (DLP™) systems. The chip has a 1920 × 1080 array of pixels, and incorporates two recently introduced improvements – DarkChip2™ and SmoothPicture™ – and a new one called DynamicBlack™. DarkChip2 increases the CR by reducing the size of the pinhole in the middle of each mirror and further reducing the gap between adjacent mirrors, thus reducing scattered light.

SmoothPicture™, said Frank J. Moizio, Worldwide Strategic Marketing and Business Development Manager for DLP Business Products, is "a system-level technology that delivers a film-like image without any pixel structure." DynamicBlack™, also a system-level technology, enhances CR in dark scenes by controlling light based on scene content. The CR can go as high as 5000:1 in dark scenes, Moizio said. He would not say any more, but the description suggests Fergason's System Synchronized Brightness Control (SSBC).

The xHD3 chip could be seen in one Samsung prototype in the TI booth – a 61-in. HDTV rear-projection unit using a single 0.9-in. chip. The image was impressive – sharp, with high contrast and a nice sense of depth – and it was bright enough. The white point was noticeably blue. There was substantial noise in the image, but that was true for most of the displays in the electrically noisy CES environment.

The HD3 chip is an evolution of the HD2, which was designed for less-expensive consumer television. Both chips have 1280 × 720 pixels, but the HD3 is only 0.55 in. on the diagonal, which should make it possible to build even more economical systems. The HD3, like the xHD3, makes use of DarkChip2™ and SmoothPicture™.

Ken Werner

Fig. 5: Thomson introduced its RCA Scenium "Profile" 61-in. DLP™ rear-projection HDTV, which is less than 7 in. deep.

Texas Instruments' booth contained a variety of DLP rear and front projectors made by its customers. Among the most striking was a 61-in. RCA Scenium "Profile" rear-projection HDTV that was only 6.85 in. deep (Fig. 5). This attracted substantial attention, and led to claims that DLP rear projectors can now be hung on the wall as easily as large PDPs and LCDs.

The light engine and optics in the Scenium rear projector were designed by ***In Focus Corp.*** (Wilsonville, Oregon), which had its own version in its booth. RCA (a brand of Thomson, with U.S. headquarters in Indianapolis, Indiana) made the cabinets for both versions.

Back at the Texas Instruments booth, Frank Moizio said that they were also formally introducing their new DDP2000 ASIC that integrates OSD, scaling, motion-adaptive de-interlacing, auto-sync, and noise-reduction algorithms for text and video. The ASIC was already being used in some customer products, such as Dell's $899 SVGA front projector. Texas Instruments' goal is for the ASIC to permit customers to build DLP systems with higher-quality images and lower system cost.

Moizio is optimistic about the future of consumer front projectors for non-home-theater use, citing data from Pacific Media Associates that the home-entertainment front-projector market would grow from 187,000 units in 2003 to 444,000 units in 2004.

Texas Instruments announced increased production of DMD chips and DLP subsystems, announcing production relationships with DongbuAnam Semiconductors and Amkor Technology.

LG Electronics subsidiary ***Zenith*** had two pairs of 44- and 52-in. rear-projection TV/monitors in the LG booth, one pair using three 0.7-in. LCD panels and one pair using DLP. A comparison of the two 52-in. models showed the DLP version to be brighter and featuring blacker blacks.

Intel Wades In

After a shift in momentum to DLP technology over the last few years, there is renewed optimism and activity in the LCoS camp. Most dramatically, in an address delivered at CES on January 8, Intel President and COO Paul Otellini, said that Intel (Santa Clara, California) will begin producing LCoS chips for rear-projection television this year. The imagers will be available in 1280 × 720- and 1920 × 1080-pixel formats.

Intel expects its LCoS technology, code-named Cayley, to be available in large-screen displays as early as this year, and for costs to decline so that end-user price points of less than $2000 will be possible next year. With its "excellent picture quality and high-volume consumer price points," says Intel, its LCoS technology can help high-definition rear-projection-TV manufacturers achieve significant sales volume beginning in 2004–2005. Although Intel obviously brings impressive resources to this task, many other companies have found that mating liquid-crystal cells with an IC in production quantities – and obtaining defect-free devices that have consistent characteristics – is not as simple as it appears.

Brillian Corp. (Tempe, Arizona), the pioneering maker of LCoS-microdisplay chips, was showing in its suite a complete 65-in. rear-projection TV, which used three of the company's imagers in an UltreX-3™ light engine made by OCLI, a subsidiary of JDS Uniphase located in Santa Rosa, California. The image was beautiful. There were no motion artifacts from where I was sitting, and the contrast seemed very high. Brillian has claimed an on-screen CR of 2500:1.) Semiconductor Manufacturing International Corp. (Shanghai) is fabricating the wafers for Brillian. According to President and CEO Vince Sollitto, Jr., Brillian intends to sell the projector for private labeling to companies that supply professional audio-video installers. According to Sollitto, many of those companies and the installers they serve have told him that Brillian's display offered "the best image in the show." Building its own complete rear-projection display represents a new marketing strategy for Brillian, which not long ago saw itself as solely a maker of LCoS imagers.

CES is a large, rich, vibrant, and glitzy trade show. It is also a place where lots of display-related products are introduced and where, just behind the scenes, a lot of technology is discussed. It has become an extremely important event in the annual display calendar – even though "display" does not appear in its name.

The next CES will be held January 6–9, 2005, in Las Vegas. At least one hotel is already fully booked for the event. ■

backlight

continued from page 44

If that were not enough, the applications that come with the new OS do not support the industry-standard driver format for my scanner; and the wonderful document-management software I have come to rely on does not (and will not) support the new OS at all. Moreover, the new OS has crippled my ability to use my legacy DOS word-processing program. The screen-window size allowed by the program is just a little smaller, in fact, than the image on a 13-in. CRT.

"A legacy DOS word processor?" you ask? It's time to admit that I do not particularly like the point-and-click model of computer interaction. With its disjunct between hand and eye, it is a clumsy half-measure, not an elegant human interface.

It is at times like these that I think about an inspiring talk I heard about 15 years ago at, if I remember correctly, a MacWorld conference in Boston. The presenter foretold the imminent arrival of modular software that users could easily hook together into configurations tailored to their needs. The vision was one of a new breed of computers, truly personal computers that adapt to what we want to do and how we want to do it. Hmmm, maybe I still have that 8-MHz machine down in the basement somewhere. It might even let me use my scanner again. ■

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continued from page 4

The standard also sets specifications for Class III and IV panels. Class III units can have up to five bright pixels, 15 dark, and 50 subpixel defects per million pixels, and up to five subpixel clusters in the 5×5-pixel-matrix range. Class IV permits hundreds of defects per million pixels.

The ISO 13406-2 standard is better known in Europe than in the United States, but many LCD-monitor vendors acknowledge it. For example, NEC–Mitsubishi asserts that all their LCD-monitor products meet or exceed the Class II standard for pixel defects. Other manufacturers are less specific, simply claiming that their products are "ISO 13406-2-compliant," which does not tell the buyer much about their pixel-defect policy.

The ISO standard has a number of limitations. It does not explain whether the permissible defects are prorated: Does a panel with 1.5 million pixels get one-and-a-half times the defects allowed for Class II qualification? Also missing are details on precisely how the defects are to be defined and measured. The biggest problem of all, however, is that LCD-panel production has outpaced the standard, and now the granularity of the classes is too coarse to be of any use. Few buyers can afford the cost of a guaranteed defect-free Class I panel, yet few would be satisfied with anything less than what Class II permits.

Another factor is that unlike a rose – which is a rose is a rose – a defect is not always a defect. As pixel counts increase and pixel pitches decrease, a single pixel defect can be more and more difficult for the end user to perceive. A single stuck pixel on a small high-resolution panel might be more difficult to spot than would a stuck subpixel on a larger lower-resolution panel. So, perhaps a classification system should take this into account.

But who can come up with such a system? Fortunately, there are now two groups actively grappling with related issues. One is the Standard Panels Working Group (SPWG) (www.spwg.org), which published a draft of their 3.0 specification in December 2003. This specification does address a wide variety of pixel defects, but fails to quantify any of them. The other group is the new VESA Panel Committee (www.vesa.org/membership_committees_Panel.html), which grew out of a Special Interest Group (SIG) that was started in 2003. This group is focusing on mechanical issues such as standardized mounting holes and other dimensions, and does not address defects at all.

Both of these groups are in a position to tackle the knotty problem of making pixel-defect policies more understandable – and palatable – to the end-user buying LCD-panel products. The SPWG has a leg up on the process by defining different types of visible defects in their existing draft standard. The VESA committee has a longer way to go, but the organization has a proven and trusted track record in sorting out nasty technological problems for the direct benefit of buyers as well as the benefit of the display industry as a whole. Remember how they solved the SVGA timing issue, or the problem of mounting LCD monitors on aftermarket stands, or the potential Balkanization of the digital display interface. VESA has the clout and capability to solve this problem, if it has the conviction.

I recognize that this is not a simple matter. The quality standards specified in contracts between display manufacturers and their suppliers are complex and sometimes a matter of proprietary interest. These manufacturers may resist being more forthcoming to consumers about just how many bad pixels it takes before they will deem the whole product defective.

But this is an important issue for consumers, and it's only about to get worse. So far, most of the panels have been sold in notebooks and computer monitors, in markets where the buyers are fairly savvy about technological issues. Yet even these people are confused and frustrated by the arcane pixel-defect policies that they encounter. What's going to happen when the buyers are less knowledgeable, but investing larger sums of money in each purchase and viewing the images for more than just spreadsheets and Web browsing? The LCD industry is banking on growth from television sales, and I guarantee that these buyers will be less tolerant of and understanding about defects than your average computer user.

The time to provide consumers with a useful classification system of LCD products based on pixel-defect policies is now, before the flow of complaints becomes a flood that damages the reputation of the entire industry. ■

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backlight

Twenty Years a PC Curmudgeon

by David Lieberman

Having just upgraded to a new PC, I realize that it has been just about twenty years since I started using a computer. Why is it that when somebody acquires a new house, car, or TV, people offer their congratulations, but when it is a new computer, what they tend to provide are condolences? I will tell you why. It is because a computer upgrade often requires a long and tedious process to get back to where you were before the upgrade, if you are ever able to get back there at all.

I would like to note up front that I upgraded because I had to, not because I wanted to. Some new software programs I added to my old machine were simply too much for the hardware, although it is only three years old. It appears that once you climb on the treadmill of ever-more-complex operating systems (OSs) eating up the increased MIPS of ever-faster processors and increased megabytes of ever-denser memory, you're stuck. This is not a treadmill I am particularly happy to be on.

Having just been obsoleted by technology, I decided I had better max out my new PC, so it has a 2+ GHz microprocessor, four times the system memory of its predecessor, and the latest-generation OS. I am very pleased that this computer boots up and opens programs so much faster than my previous machine. But when you consider the big picture, all this has accomplished is to bring me back to the mode of operation I enjoyed back in the early 1980s. That is to say, the wait time was just about the same when my PC was an 8-MHz machine running DOS.

As for the march of peripherals, the complement of devices on my previous PC was nearly perfect, thank you, and I would have been content to carry their capabilities over as they were. I had an acceptable keyboard, a mechanical mouse that only clogged about once a month, a nice big LCD monitor, and a wonderful color MFP (multifunction peripheral), *i.e.*, a combination printer, scanner, facsimile, and copier. If I remember correctly, when I started off in the early 1980s, my machine was hooked up to a 13-in. CRT monitor, a dot-matrix impact printer, and a keyboard (but no mouse).

Post upgrade, I am now crippled in the use of my peripherals. The one plus is that I have replaced the cloggable mouse with an optical mouse, and both the mouse and new keyboard are wireless. That provides a real benefit in uncluttering the desktop and thinning down the rat's nest of cabling. That is the type of upgrade, like replacing a CRT with an LCD monitor, that makes it hard to go back.

But as far as my monitor and MFP are concerned, how I wish I could go back to my previous PC! Because of the agonies of incompatibility, these peripherals are no longer what they used to be, although I simply unplugged them from the old machine and plugged them into the new. It seems that the drivers for my new OS and this particular MFP are, to put it gently, in an immature state. Although one claim to fame of this OS is that it does not recurrently crash like its predecessor, it has a new quirk as far as my MFP is concerned. It frequently fails to recognize the existence of the MFP, so I have to reboot – as if I had just crashed.

continued on page 36

calendar

24th International Display Research Conference (Asia Display 2004). Contact: SID HQ, 408/977-1013, fax -1531, e-mail: www.sid.org.
August 24–27, 2004 Daegu, Korea

Advanced Display Technologies Symposium (FLOWERS 2004). Contact: Prof. A. Smirov, +375-17-2398858, fax -2398486, e-mail: smirov@gw.bsuir.unibel.by.
September 7–10, 2004 Minsk, Belarus

EL2004 International Conference and Workshop. Contact: Adrian Kitai, McMaster University, e-mail: el2004@mcmaster.ca.
September 20–23, 2004 Toronto, Canada

48th Annual Human Factors & Ergonomics Society Meeting. Contact: HFES, 310/394-1811, fax -2410, e-mail: info@hfes.org.
September 20–24, 2004 New Orleans, LA

PC Expo/Techxny 2004. Contact: CMP Media LLC, 1-888-234-9476, e-mail: www.techxny.com.
October 3–7, 2004 New York, NY

The Americas First Display Engineering and Applications Conference (ADEAC 2004). Contact: Mark Goldfarb, PCM, 212/460-8090 x202, fax -5460, e-mail: mgoldfarb@pcm411.com.
October 25–27, 2004 Ft. Worth, TX

12th Color Imaging Conference 2004. Contact: IS&T, 703/642-9090, fax-9094, e-mail: info@imaging.org.
November 9–12, 2004 Scotsdale, AZ ■

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