FLEXIBLE DISPLAYS ISSUE

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Flexible Displays: Just Around the Bend

FLEXIBLE DISPLAYS AS USER-INTERFACE DEVICES

FLEXIBLE DISPLAYS: NOT FAR OFF BUT FAR TO GO

A FLEXIBLE UNIVERSAL PLANE

CHOLESTERIC-BASED REFLEX LCDS ON R2R

Plus

CES 2011 Review

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ON THE COVER: *The pace of flexible-display development has been accelerating over the past few years. Large R&D organizations and universities associated with the display industry are putting unprecedented efforts into developing flexible electronic technologies. There is great creativity going on in identifying new uses for flexible displays, which is beginning to create the demand that has been lacking for so many years.*

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Next Month in *Information Display*

Touch Technology Issue

- Optical Touch Technology
- High-Performing Pro-Cap Touch System
- The Dichotomy of Touch
- Touch-Screen Market Assessment

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editorial

Strength and Flexibility

Stephen P. Atwood

Welcome to our February 2011 issue, which is focused on the theme of Flexible Displays. This month we welcome back veteran contributor and past-SID-President Paul Drzaic as our Guest Editor. As usual, Paul has done a great job, assembling a trio of technology articles that we really hope you enjoy. I won't steal Paul's thunder on the introductions; you should read them for yourself in his Guest Editorial.

However, I do want to note that I was very pleasantly surprised when I read the article from Kent Displays titled, "Beyond Conventional Display Applications: Cholesteric Reflective LCDs." In this article, the author reveals that Kent Displays is now manufacturing its cholesteric liquid-crystal-based displays on a fully automated roll-to-roll production line. An LCD developer is making its displays with a roll-to-roll process, and in North America as well! It's true that these are passively addressed displays, which avoids the tricky issue of fabricating active-matrix switches on the rollable substrates, but this is still a real roll-based process in volume production. It has been the goal of so many manufacturers to reach this stage and realize the myriad of potential cost savings associated with this approach and I think this is an exciting milestone to note in our industry.

Roll to roll is just one of the headlines this year on the flexible front. To help you get the broadest possible view, we enlisted industry analyst Paul Semenza from DisplaySearch. In his article, "Flexible Displays: Still a Lot to Learn," Paul covers the gamut, including flexible-backplane materials, active-matrix backplanes, liquid-crystal and OLED technologies, inorganic EL, and even a curved plasma display. It's a busy area, and Paul did a good job sorting through it all for us.

While we were putting this issue together, the annual Consumer Electronics Show (CES) was playing in Las Vegas to an audience of over 140,000 attendees – most of which will hopefully be energized to buy some of the new toys and help boost this year's economy. We recruited veteran reporter Alfred Poor to take a look for us and he came back with a number of interesting observations. He noted especially the plethora of new 3-D TVs, some of which are now using patterned retarders to enable the use of passive glasses instead of the more common shutter glasses we have discussed many times in other months. The move to passive glasses is a good one, putting the user experience more on par with that in a local 3-D movie theater, as well as reducing the cost of the glasses to mere dollars from hundreds of dollars per pair. Television viewing is a family experience, and the cost of the glasses seems to be a meaningful deterrent to adoption of these sets. Be sure to read through Alfred's CES coverage, and I'm sure you will find plenty to get excited about with regard to displays.

One last thing I want to mention is our article on the Latin Display 2010 conference, contributed by Ken Werner and Alaide P. Mammana. The team leading the Brazil chapter of SID has been working for years to further the education of engineers in display technology as well as foster investment in display-related business in that region. A big part of this effort is the Latin Display conference, which has grown significantly over the past few years into a full three-day event. Of course, holding it in conjunction with the International Display Research Conference (IRDC) this year did not hurt, but as you can see from Ken and Alaide's comprehensive review that there was plenty of

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industry news

e-Readers Get Color(ful)

If there is any product right now that is enjoying relentless momentum in terms of market penetration, e-Readers are that product. Despite the predictions of some industry experts that the iPad would render the Kindle and other e-Readers obsolete, 2010 sales were brisk, especially if the proclamations of retailers and analysts are to be believed. While characteristically reluctant to reveal specific figures, Amazon stated that its latest Kindle had replaced *Harry Potter and the Deathly Hallows* (the final book in the wildly popular series by J. K. Rowling) as its top-selling product of all time. Barnes & Noble reported record holiday sales for 2010 and attributed the bulk of that success to its NOOK e-Reader.

While overall 2010 figures have not yet been reported, a recent Gartner Group study predicted that e-Reader sales would reach 6.6 million units in 2010, up 79.8% from 2009 sales of 3.6 million. In 2011, according to Gartner, sales will exceed 11 million, a 68.3% increase from 2010.[1] But, in fact, you do not need to peruse the reports of analysts to gauge the success of e-Readers: you only have to look around the cabin of any U.S. domestic flight to see that the little devices have proliferated like mushrooms, especially compared to a similar flight a year ago.

The LCD-based Barnes & Noble NOOKcolor e-Reader was commercially released in October 2010 for $249. Image courtesy Barnes & Noble.

Must Have Color

Successful as e-Readers are, the general notion is that they must have color in order to maintain momentum. E Ink, for example, which makes the imaging film in the monochrome Amazon Kindle and numerous other e-Readers, has been showing its color display prototypes at Display Week for at least a couple of years. Now, E Ink has officially introduced Triton, the color version of its monochrome technology. According to an E Ink spokesperson, Triton is just like E Ink's latest-generation imaging film, Pearl, except that it uses color filters atop the monochrome film. Triton is in mass production and will soon be available in commercial products such as the Hanvon e-Reader, which is scheduled to ship around late Q1 2011 for approximately $450.

Another color contender that showed up at CES this January was Qualcomm's mirasol® color e-Reader, which is based on the company's reflective technology. The device was also shown at CES 2010, and while some industry observers noted that this year's prototypes look closer to commercialization, Qualcomm has yet to set a date.

In a way, it can be argued that color already has come to e-Readers – if you include LCDs. The NOOKcolor from Barnes & Noble, for example, was introduced toward the end of 2010 and has vibrant color courtesy of an IPS panel from LG. The NOOKcolor retails for $249. You could even argue that tablets such as the iPad are, or can be considered, color e-Readers because many people use them for that purpose.

Adding another potential technology to the mix is Samsung, with its recent acquisition of Liquavista, a Netherlands-based company that makes an electrowetting technology that operates in transmissive, reflective, transparent, and transflective modes. Potentially, this technology can enable colorful displays with reduced power consumption. At press time, Samsung was not commenting on the acquisition or any future products, but it seems reasonable to assume that plans for some type of e-reading/tablet device are in the works.

Triton, E Ink's color imaging film, will be powering a number of devices that will become commercially available this year. Image courtesy E Ink.

The merging of e-Reader, tablet, and display technologies may be where all this is headed, at Samsung and elsewhere. The current tradeoffs are that reflective e-Readers offer colors that are fairly muted. LCDs have brighter color, but use more power and are not as sunlight readable. Readers such as the Kindle also mimic paper as a reading experience, which for most people is easier on the eyes than reading from a backlit device. As these different technologies are developed to overcome their relative shortcomings, their confluence will undoubtedly make for a better electronic-reading experience. Whatever technology "wins," the consumer will be the biggest winner.

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– Jenny Donelan

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guest editorial

Flexible Displays: Fascinating and Not As Far Off

by Paul Drzaic

A display fabricated on film is one of those ideas that has inspired both the general public and the display industry. Flexible displays of one sort or another are commonly found in science fiction and fantasy, most recently appearing in both the book and film versions of the *Harry Potter* series. Displays with flexible capabilities have been worked on for more than three decades within the display industry. They have certainly not suffered for lack of interest.

Nevertheless, flexible displays are not common in real-world applications. Most people would be hard-pressed to identify examples of flexible displays they have seen in real life. There are few other areas of display technology with such a lengthy gap between R&D demonstrations and commercial reality.

Part of the reason is that making flexible displays is difficult. Plastic films are not the ideal substrate for building highly precise electronics. Many displays are rather fragile, and plastic films do not provide the environmental protection that glass sheets do. It is also true that the dominant display technology, polarizer-based nematic liquid-crystal displays, do not work well in a flexible package.

A bigger challenge has been the success of mainstream active-matrix liquid-crystal display (AMLCD) devices. Every year, these displays improve in quality, shrink in cost, and find more and more applications. Expectations for displays grow more demanding every year. If consumers are going to give up quality, size, or low cost just to obtain a flexible display, there had better be a really good reason for the flexibility. To date, neither the industry nor the user community has been effective in identifying that flexible display "killer app."

Nevertheless, the pace of flexible-display development has been accelerating over the past few years. A number of factors are at play. New materials enable new types of devices. Large R&D organizations and universities associated with the display industry are putting unprecedented efforts into developing flexible electronic technologies. There is great creativity going on in identifying new uses for flexible displays, which is beginning to create the demand that has been lacking for so many years. With these thoughts in mind, this month's *Information Display* takes a look at some examples of flexible displays that just may make the leap from laboratory to widespread adoption.

Janglin Chen and Jia-Chong Ho describe how ITRI in Taiwan is developing a new process for fabricating high-resolution flexible displays. One of the problems in the development of flexible displays is the cost associated with scaling up new fabrication technologies. The work from ITRI describes an innovative way of using existing fabrication facilities to build flexible displays at high yield and low cost. This work was recognized by *The Wall Street Journal*, which awarded it a Gold Prize in its Technology Innovation Award competition.

I think it is important to consider that flexible displays may enable brand-new applications, rather than serving as flexible replacements for displays already in use. The paper by Asad Khan describes a number of emerging display applications, ranging from flexible electronic notepads to electronic "skins" for devices, that are enabled by the flexible-display technology developed at Kent Displays. If any surface can be turned into a display, then we have enabled the potential of making those surfaces smart and interactive.

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A Flexible Universal Plane for Displays

FlexUPD is the Industrial Technology Research Institute's flexible-universal-plane solution for quality flexible displays and other non-display applications. Using FlexUPD technology, ITRI successfully integrated a flexible TFT backplane with AMOLEDs and received The Wall Street Journal*'s 2010 Technology Innovation Gold Award.*

by Janglin Chen and Jia-Chong Ho

FLEXIBLE DISPLAYS represent a mega-trend within the next-generation display market because of their light weight, sturdiness, and shape-forming capabilities. In order to create flexible displays, however, it is necessary to develop a corresponding flexible substrate material, along with a process that includes chemical resistance, thermal stability, endurance in high temperatures and pressures during the TFT process, and moisture-barrier properties. Active-matrix organic light-emitting-diode (AMOLED) technology is among the most attractive display technologies for building on a flexible substrate because it is self-emissive and has attributes such as high video rate, wide color gamut, low power consumption, and, most importantly, simplicity in structure.[1]

However, although the idea of flexible AMOLED displays is intriguing, the development of the necessary flexible substrate remains a challenge. Many substrates, such as ultra-thin glass, plastic, and stainless steel, have been tried but without commercial success because they lack the proper surface properties, thermal stability, or mechanical properties, or because they cannot sustain the stringent TFT processing conditions.[2-4] LG has focused on the development of metal-foil substrate for flexible displays because of its high thermal stability, low cost, and low coefficient of thermal expansion (CTE).[5] However, the surface of the foil is too rough to be used directly as a flexible substrate and additional polymer coating for surface smoothing is needed, which makes the technology less attractive. Thin glass as a flexible substrate has also been tried, but has not met with commercial success due to its brittleness. Plastic films on glass, which are being developed by many companies and research groups, are now considered as one of the most promising substrates for flexible displays.

Currently, plastic substrates are prepared by laminating or coating a plastic layer on glass carriers, followed by fabricating TFT devices on the substrates, then releasing the substrate with a TFT backplane from the glass. The most daunting challenges of these approaches are finding the right substrate material and also developing the de-bonding technology to remove the plastic film from the glass. As shown in Fig. 1(a), a representative structure for a laminating approach consists of a plastic layer such as PC, PET, PEN, PES, PI, *etc.*, adhesive glue, and glass. This approach, in general, has issues of poor alignment, residual glue, and process temperature limitation,

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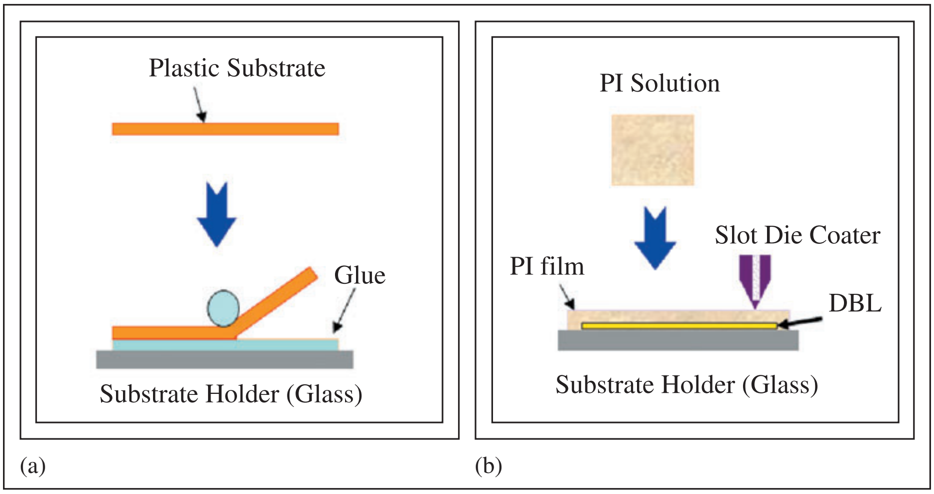

***Fig. 1:** Flexible Universal Plane Technology relies on two key innovations: (a) the substrate and (b) a de-bonding layer (DBL).*

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which have rendered the plastic film lamination approach less feasible.

With the approach of coating a plastic layer onto the glass substrate, as shown in Fig. 1(b), those issues have been eliminated or made less severe. However, the de-bonding of the flexible TFT backplane is still a challenge. Recently, two de-bonding methods for the coating-type substrate technology have been developed; namely, the Electronics-on-Plastic by Laser Release (EPLaR) process developed by Philips[6,7] and the FlexUPD Flexible Universal Plane for Display (FlexUPD) by ITRI.[8] The EPLaR technique uses a laser to remove the substrates from the glass carrier. The equipment cost of the laser is high and the throughput is slow. ITRI's FlexUPD approach uses a de-bonding layer for release of the substrate and should be the more viable approach to enabling the mass production of thin, low-cost flexible displays. The possible value of the process was recognized just recently, when ITRI's FlexUPD was presented with a Gold *Wall Street Journal* 2010 Technology Innovation Award (the top prize) for innovation, potential impact, and promise for commercialization.

By using FlexUPD technology, flexible displays can be processed in current TFT manufacturing facilities, many of which have been fully depreciated. Consequently, the capital investment in order for the industry to quickly adopt this technology is low. The developed FlexUPD flexible substrate technology is a platform technology, which allows it not only to be applied for displays, but also for non-display applications. In principle, the FlexUPD technology can be used for OLEDs, LCDs, EPDs, and other display types. And it can be applied to applications such as flexible OLED lighting, flexible photovoltaics, flexible sensor arrays, flexible x-ray sensor arrays, and more.

Flexible Universal Plane for Display Technology

ITRI developed the FlexUPD plastic substrate technology by coating a polyimide solution directly onto the glass substrate with a de-bonding layer (DBL) as shown in Fig. 1(b), followed by fabricating TFT devices on the said substrate. Then the substrate was released from the glass. The DBL provides a weak interface between it and the plastic film, which allows the film to be easily released after the TFT process. Two key innovations make the FlexUPD a success: the flexible substrate material and the de-bonding technology.

Table 1: PAA-type PI and ITRI's PI are compared in terms of chemical resistance, transparency, and other attributes.

	PI (PAA type)	ITRI's PI
Tg (°C)	>300°C	>300°C
CTE (ppm/°C)	30–40	50–60
Chemical resistant	Excellent	Good
Transparency (%)	< 30	> 90
Surface visibility	Both sides visible	Top side visible
Maximum drying temperature	>300°C	<250°C
Time of process	>3 hours	<1.5 hour

Flexible Substrate Material

Polyimide (PI) is an excellent choice for a coating-type substrate material due to its good thermal and chemical resistance. In general, PI is prepared by first reacting a diamine monomer with a dianhydride monomer in a polar solvent to prepare a precursor poly(amic acid) (PAA). Then the PAA is coated on glass and subjected to thermal treatment for imidization. Typically, the thermal imidization is run at high temperature (>300°C) and the total processing time is longer than 3 hours, which are rather stringent processing conditions. At ITRI, a colorless polyimide is synthesized with non-fluoro monomer, which can be processed at <250°C in less than 1.5 hours. Moreover, it exhibits good light transmittance (90%), high glass-transition temperature (T_g>300°C), and good chemical resistance. The material characteristics of PAA-type PI and ITRI's PI are compared in Table 1.

Table 2: Properties of the silica/PI hybrid film include a 90% light transmittance at 550 nm.

Sample name	SiO_2/PI hybrid film
Tg (°C)	>400
CTE (ppm/°C)	28
Young's Modulus (GPa)	4.3
Light transmittance (% at 550 nm)	90
Haze	0.01

A new inorganic-dominated silica/polyimide (PI) hybrid film has also been successfully developed for the high-performance substrate.[9] The high inorganic content (>60 wt.%) brings high modulus, thermal resistance, and low coefficient of thermal expansion (CTE) to the film. Table 2 summarizes the properties of the silica/PI hybrid film.

Flexible Substrate De-Bonding Technology

This novel flexible-substrate technology is compatible with existing TFT infrastructures and processes. Figure 2 is a schematic illus-

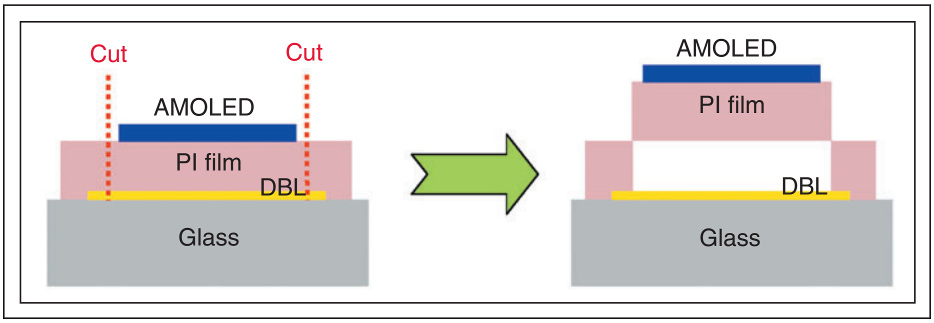

Fig. 2: In this flexible-substrate schematic, at left, the edges of the PI film are in direct contact with the glass during processing, which reduces the possibility of thermally induced misalignment. Cutting is done along the circumferences of the PI layer inside the edge of the DBL. Then, due to the weak adhesion of DBL with PI film, the PI layer can be easily separated, as shown at right.

tration of the de-bonding technology, which differs from conventional laminating technology in two aspects. First, the solution-type PI is coated directly onto the glass carrier with a de-bonding layer (DBL). The distortion of the PI substrate due to thermal expansion can be kept to a minimum throughout the TFT process and the PI film can be released from the glass after the TFT process. Secondly, unlike the pre-formed foil substrates, the thickness of the coated PI film can be easily controlled by metering the solution lay-down.

As shown in Fig. 2, the edges of the PI extend over the underlying DBL and are in direct contact with the glass, which allows the PI layer to be securely adhered to the glass carrier throughout TFT processing, where thermally induced misalignment might otherwise occur.

With the developed PI and DBL, the PI substrate can be securely adhered to the glass carrier during the entire TFT process so that there is no misalignment problem. Besides, after the designed TFT processes are completed, the PI substrate with a TFT backplane can be easily separated from the glass. For this de-bonding method to be applied in mass production, an automatic flexible-substrate de-bonding procedure is needed. Consequently, a custom-designed flexible-substrate de-bonding apparatus facilitated with a vacuum system was developed for releasing the flexible display. The prototype of the apparatus is shown in Fig. 3.

Based on this novel flexible-substrate technology, we were able to develop flexible TFT backplane technology, flexible OLED technology, and flexible touch technology.

Fig. 3: This flexible display de-bonding apparatus is a prototype.

Flexible Substrate for AMOLED Displays

When a plastic substrate is used for the flexible OLED application, the water-vapor transmission rate (WVTR) of plastic substrate becomes critical. A general PI film has a WVTR of 5 g/m^2/day and higher, whereas for OLED applications, the WVTR of the substrate has to be lower than 4×10^{-5} g/m^2/day. In order to overcome such a deficiency, a barrier layer was introduced. With our barrier technology, the WVTR of PI can be improved to less than 4×10^{-5} g/m^2/day. Moreover, this barrier property suffered only a minor drop, to 8×10^{-5} g/m^2/day, after the flexible panel had been bent 1000 times at a radius of 5 cm. The WVTR of intrinsic PI and PI with the barrier is compared in Table 3.

In our flexible-display construction, the top-gate TFT arrays were first integrated with a two-transistor, one-capacitor circuit in the backplane, and then the color OLED was deposited on the TFT backplane to form an AMOLED display. Photographs of a 4.1-in. (108 × RGB × 240) flexible color AMOLED display under bending (curvature radius ~ 5 cm) and a 6-in. (320 × RGB × 240) flexible color AMOLED display are shown in Figs. 4(a) and 4(b), respectively. The total thickness of the 6-in.flexible AMOLED display is about 65 µm, which can be bent at a curvature radius of 5 cm for 15,000 times without deterioration in performance.

Flexible Touch AMOLED Display

A flexible touch AMOLED display was also successfully developed by ITRI. With the approaches described above, the flexible TFT backplane, the flexible OLED, and the flexible touch film could be integrated on the

Table 3: The water-vapor transmission rates of intrinsic PI and PI with a gas barrier are compared.

		Testing Environment 60°C, 90%RH	
Sample	**Film thickness (µm)**	**Before bending WVTR (g/m^2/day)**	**After bending (@ R=5 cm, 1000 times) WVTR (g/m^2/day)**
Intrinsic PI	15–30	> 5	>5 (measured using MOCON instrument[10])
PI with gas barrier	0.3–1.5	4×10^{-5}	8×10^{-5} (measured using calcium test[11])

(a) (b)

Fig. 4: (a) A flexible 4.1-in. (108 × RGB × 240) color AMOLED and (b) a 6-in. (320 × RGB × 240) flexible color AMOLED in a simulated newspaper demonstration.

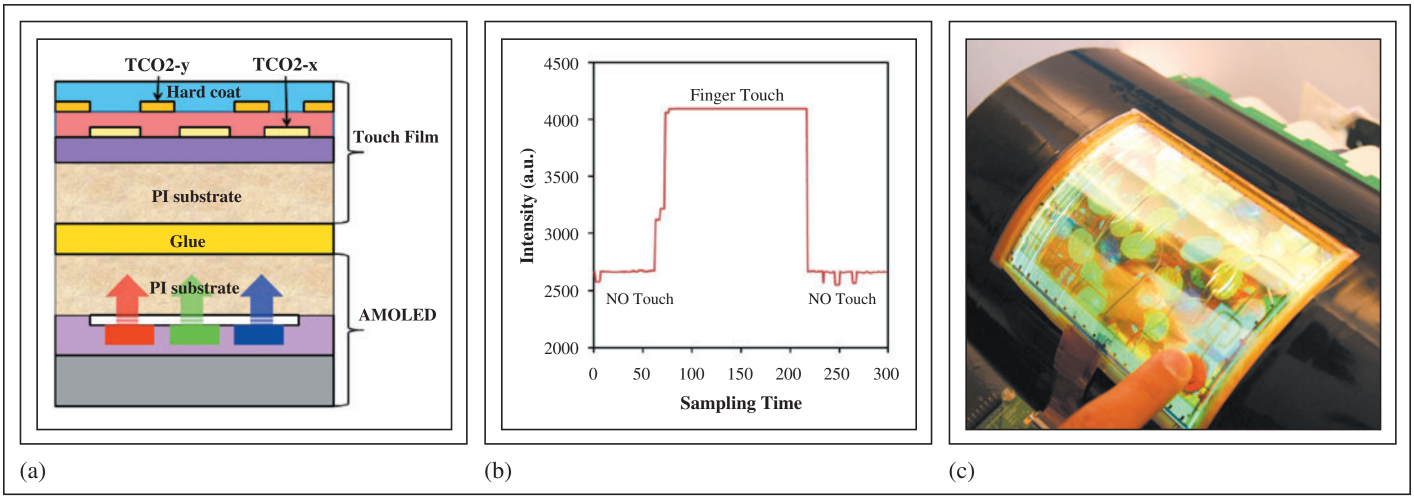

***Fig. 5:** (a) An integrated structure of a flexible AMOLED display and projective-capacitive touch-sensing film. (b) Signal intensities of the touch-sensing panel with and without finger touch. (c) A prototype of the flexible touch AMOLED display in a curved configuration.*

transparent PI substrate using FlexUPD technology. Figure 5(a) shows schematically the structure of the flexible color AMOLED with ultra-thin touch-sensing film. Profiles of the signal intensities of the touch-sensing panel with and without finger touching were measured and plotted as shown in Fig. 5(b). With a high S/N ratio, the touch signal can be reliably distinguished from noise. We have successfully integrated and demonstrated the performance of an ultra-thin touch-sensing film with a flexible color AMOLED as shown in Fig. 5(c), which, to the best of our knowledge, is the first flexible touch AMOLED display demonstrated in the world.

A Technology with Scalability

Using the novel FlexUPD technology, ITRI was able to demonstrate a flexible AMOLED display. The technology used includes a flexible substrate material, a de-bonding layer material, de-bonding process, flexible TFT process, and flexible OLED process. With ITRI's approaches, the PI substrate can be used in high-temperature TFT processes, and the alignment shift can be controlled within 2 µm. In addition, the flexible display can be easily released from the glass carrier without any damage. We believe that the technology can be readily scaled up to produce larger-sized flexible substrates (larger than Gen 4) on current TFT display-manufacturing facilities.

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Beyond Conventional Display Applications: Cholesteric Reflective LCDs

New cholesteric LC materials and roll-to-roll manufacturing processes have enabled new technologies that have, in turn, inspired new applications and products.

by Asad Khan

THE DISPLAY INDUSTRY has grown and evolved with the times. The last two decades have seen amazing new applications, from laptop computers to large televisions that are mere millimeters thin. At the same time, it is the industry that has had a romance with flexible displays for a long time. Only about a dozen years ago, flexible displays and applications started taking on significant momentum. The energy and hype in the industry has been persistent. Recently, some applications and embodiments have surfaced in limited numbers in the marketplace. These have included displays in flexible smart cards, wrist watches, *etc*. One must note that there is certainly an abundance of prototypes and technology demonstrators as well as limited low-volume releases in the market using flexible displays from organic LEDs (OLEDs) to electrophoretic displays and even conventional LCDs.

One medium for flexible displays that has found success is the bistable cholesteric technology recently branded as Reflex™ from Kent Displays. This technology has been in the market since 1996 in non-flexible applications such as industrial, digital signage, and instrumentation (see Fig. 1).

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Cholesteric displays are Bragg-reflecting devices in which the liquid-crystal material itself reflects light in the planar texture. The cholesteric liquid-crystal material is arranged

Fig. 1: Many products and prototypes have been created using Kent Displays' bistable cholesteric technology, including (clockwise from center top): digital signage, smart cards, store labeling systems, flexible color-changing skins for phones, outdoor signage, and, at center, the Boogie Board tablet.

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in a helical fashion creating so-called textures. The two textures used in bistable cholesteric displays are the planar (p) and the focal-conic (fc) textures (see Fig. 2).

The planar texture is reflective and the focal-conic texture is largely transparent, showing the dark absorbing background. Other textures that are involved in electro-optical effects are the transient planar (p*) texture and the homeotropic (h) texture. Transitions take place between these textures through external forces, such as electric fields or applied pressure, to enable operation of cholesteric displays. Phase transitions such as crystal to cholesteric or cholesteric to isotropic take place when the temperature for the system is changed.

There are a variety of passive-matrix drive schemes that can be utilized to switch the displays, and these can be run as fast as about 0.5 msec/row at room temperature. These displays can also be driven by a typical active-matrix backplane. In general, the display architecture is simple; only transparent substrates and conductors are used, with no polarizers, retardation films, backlights, *etc.*

Figure 3 shows a cross-sectional schematic illustration of a conventional TFT-LCD, a bistable rigid glass-based cholesteric LCD, and a flexible cholesteric LCD – the latter in both single-layer and stacked-type three-layer configurations. The thickness of all display types is drawn to scale to illustrate the dramatic differences among them. The benefits of flexibility, thinness, and ruggedness are obvious.

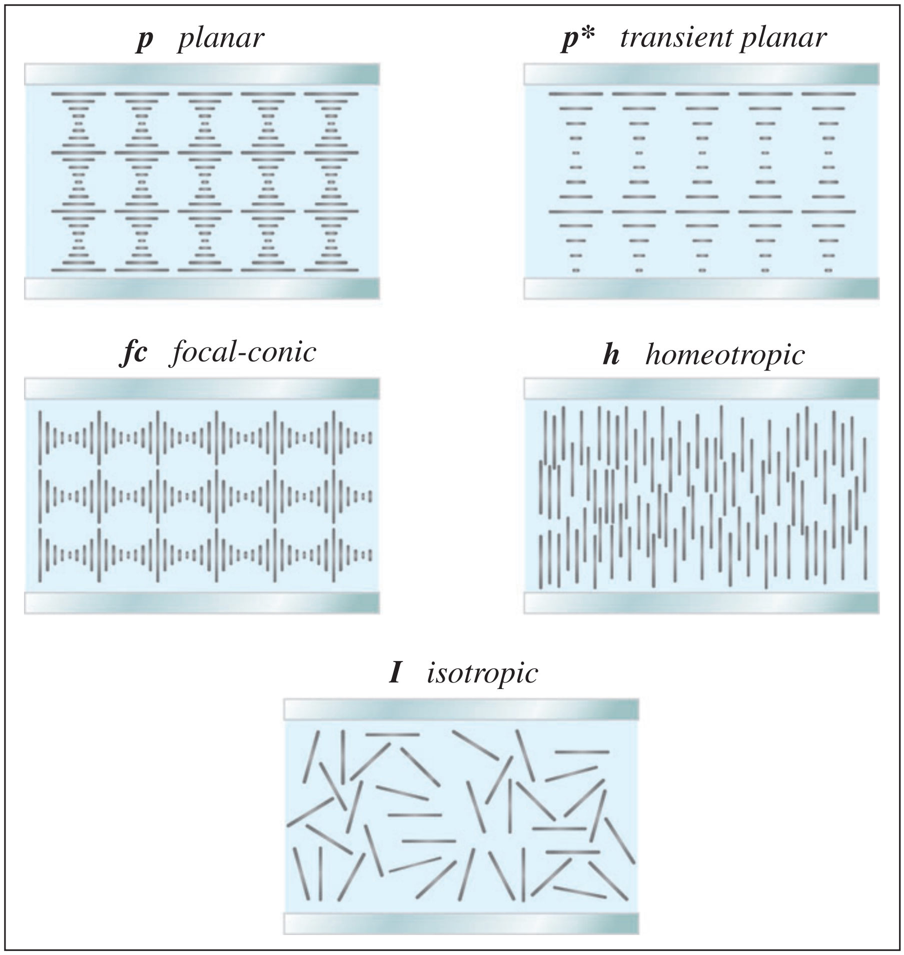

Fig. 2: Key textures include the reflective planar (p) and the transparent focal-conic (fc) states. These two textures are stable in the absence of an external stimulus (such as an electric field or pressure).

Manufacturing Advances

One of the key enabling features of encapsulated cholesteric displays is the development and execution of the necessary manufacturing processing, methods, and tools. Today, writing tablets, electronic skins, and displays for smart cards (all discussed below) are routinely manufactured at the Kent Displays' plant in Kent, Ohio, utilizing continuous roll-to-roll manufacturing. The operation runs 24 hours a day, 7 days a week, and is highly automated. Products from the manufacturing line, such as the Boogie Board, have been shipping since mid-2009. The capacity for the first-generation line has been sufficient for initial product introductions and validation. However, it is already running at maximum capacity. The next-generation line is in design and development at present.

The existence of the first fully automated roll-to-roll production line dedicated to flexible cholesteric-LC-based displays marks a key milestone toward the realization of flexible LCDs in mass production for a variety of applications. The equipment and processes that have been developed by Kent Displays have been instrumental in enabling a viable cost structure for flexible displays as well as creating the capacity and capability necessary for mass production and market entry.

Cholesteric-LC Materials and Applications

Cholesteric liquid-crystalline materials have been used in many different optical and electro-optical devices such as temperature sensors, thermometers, and high-efficiency polarizing films. Cholesteric materials have also been the subject of much research with regard to electro-optical displays. In the last decade, they have been successfully developed into bistable, purely reflective, low-power LCDs. Their high reflectivity, wide viewing angle, and low power due to bistability make them an excellent display technology choice for signage applications, handheld devices, and portable electronic readers.

Color in cholesteric displays comes from additive color mixing. Red, green, and blue primaries can be arranged vertically (stacking[1]) or horizontally (spatial[2]). Both have unique benefits and are suited for particular applications. Stacking allows for excel-

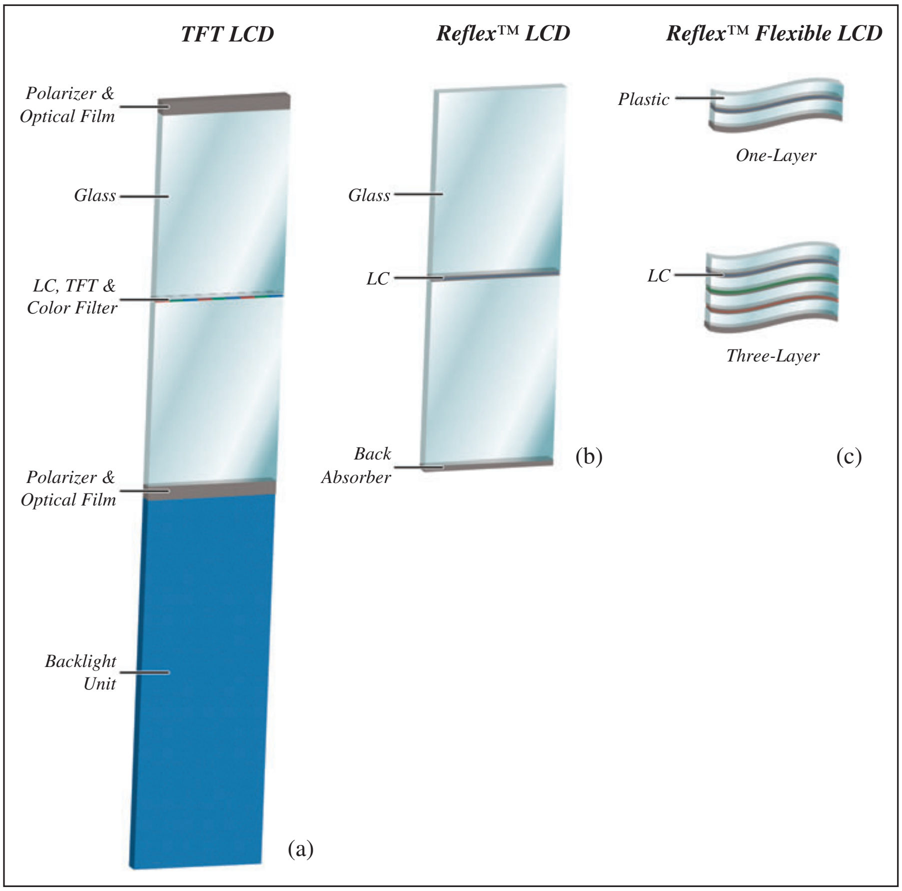

Fig. 3: This cross-sectional schematic illustration shows (a) a conventional TFT-LCD, (b) bistable rigid glass-based cholesteric LCD, and (c) a flexible cholesteric LCD, the latter in both single-layer and stacked-type three-layer configurations. The thickness of all display types are drawn approximately to scale.

lent reflectivity and brightness, whereas spatial color allows for high-contrast and low-cost architecture. Both approaches have been used. Stacking is the predominant approach employed in a variety of applications, from large-area digital signage such as that produced by Magink and AEG-MIS, to high-information-content full-color electronic readers such as those made by Fujitsu. Unconventional applications such as electronic "skins" also employ the stacking structure.

More recently, cholesteric materials have been successfully encapsulated using a phase-separation approach,[3] allowing for low-cost roll-to-roll manufacturing while maintaining the inherent properties of conventional cholesteric displays. The encapsulation dramatically ruggedizes the displays and allows for a high degree of flexibility. This then lends itself to the exploitation of applications that were not possible previously.

Because conventional display applications did not seem to fully exploit the features of these cholesteric-LC displays, new and unique applications have been explored, and the subsequent innovations led to three different product lines that share the same underlying technology: writing tablets, electronic skins, and flexible information displays.

Writing Tablets

LCD writing tablets based on Reflex technology are in many ways a replacement for chalkboards, whiteboards, and scratch paper. Since these LCD writing tablets use a pressure-sensitive display, the user does not need a special pen to create an image. Even a fingernail or other object can be used to create the desired effect.

The writing tablet display is a simple construction of flexible plastic substrates coated with conducting polymer electrodes.[4] It is made from a single pixel, so the construction and the driving electronics are therefore streamlined. Since the construction is from flexible substrates, the product is inherently more rugged than glass-based displays, although it is not meant to be flexed while in normal operation. The initial state of the display is in the focal-conic (fc) texture. External pressure causes the liquid crystal to flow, and the flow re-orients the liquid crystal in the planar texture. The area where pressure is applied therefore appears brighter than the surrounding area. Pressing the erase button triggers the electronics to apply appropriate waveforms to switch the entire "pixel" back to the focal-conic texture, where it appears dark based on the color of the back absorber.

Kent Displays entered the writing-tablet mass market in January 2010 with the introduction of its Boogie Board LCD Writing Tablet from Improv Electronics, a newly formed business unit of Kent Displays (Fig. 4). Global demand for the Boogie Board tablet was immediate and has been sustained.

Similar to all LCDs that are reflective and bistable, the Boogie Board tablet requires no power to generate or retain an image, and only a small amount to erase (supplied by a coin cell battery, which will execute over 50,000 erase cycles). The lower power nature of the Boogie Board further makes it an environmentally friendly product.

The Boogie Board can be used in the home, at the office, in the classroom, on the field, and in the car for a wide range of activities including writing memos and to-do lists, leaving reminders, practicing handwriting/arithmetic, drawing pictures, performing calculations, brainstorming ideas, charting/graphing, playing games, diagramming athletic plays, and more. The product is proving popular in schools, and also with individuals who have speech or hearing disabilities. Kent Displays is actively developing a wide range of new Boogie Board tablets and accessories for 2011. Next-generation Boogie Board tablets will feature different sizes and form factors, image-capture technology, and other new functions/capabilities.

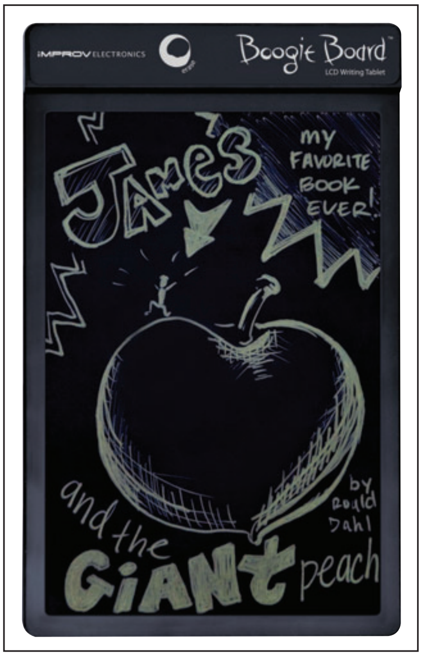

Fig. 4: This writing tablet – the Boogie Board – is the first mass-produced Reflex LCD made from all flexible materials. It has been in the marketplace since the beginning of 2010 and retails for less than $40.

Electronic Skins

Kent Displays' electronic skins utilize display technology on ultra-thin flexible substrates. When integrated onto all or part of another object's surface, typically a personal electronic device, the skin provides on-demand personalization, usually in the form of a color change that can be initiated as often as desired by engaging a switch or button.

Development of these electronic skins has been an on-going area of focus at Kent Displays for several years.[5] The skin uses plastic substrates that are similar to those in the writing tablet. They are coated on one or both sides with conducting polymer. The display is either single layer (for one color) or multiple layers (for multiple colors). Figure 5 shows photographs of a prototype mobile phone with a color-changing electronic skin integrated into the housing. Different colors are realized on the skin by electronically switching.

These skins are also manufactured in a roll-to-roll continuous process. Similar to the Boogie Board, the architecture is simple in that there is only one pixel and simple drive electronics. For multiple layers, the display is made in a stacked structure directly on the fully automated production line.

The first-generation Reflex skins display 2–8 different colors depending on the number of substrate/liquid-crystal layers. The skins can be cut into almost any desired shape and can be thermoformed to a device surface. Figure 6 shows thermoformed three-layer full-color electronic skins conformed to a spherical (complex) surface.

While the integration of skin to device represents many challenges, several methods can potentially be utilized, including lamination, in-mold decoration, injection molding, *etc.* Most of these methodologies have already been demonstrated in the laboratory.

In 2011, Kent Displays will introduce an aftermarket consumer product featuring a Reflex electronic skin. This product will be sold under the Improv Electronics name and is expected to generate consumer demand comparable to that for the Boogie Board LCD Writing Tablet. In part, due to this, the company's developers believe the push into unconventional applications for flexible displays will see significant growth in 2011.

Fig. 5: A prototype mobile phone features a color-changing electronic skin integrated into the housing. Multiple colors can be realized on the skin by electronically switching. The bare electronic skin is also shown to illustrate its flexibility.

Flexible Information Displays

The application discussed in this article that is closest to one for conventional displays is the product area dedicated to graphical and segmented displays for smart cards. These displays are made with ITO-coated plastic and are either directly (segmented) or passive-matrix (graphical) addressed. The drive schemes allow for low cost and easier integration into thin cards. The encapsulated Reflex-based materials are rugged enough to withstand ISO testing of fully integrated display/cards. Figure 7 shows conceptual ideas for smart-card displays integrated in consumer credit and loyalty/membership cards. Other applications include one-time password (OTP), loyalty, and gift cards.

The graphical and segmented displays for card applications are also manufactured using the same continuous fully automated roll-to-roll production. The input is fully patterned ITO-coated thin plastic substrates. After display production, the displays go through testing and finally bonding to electronics prior to integration into card "inlays." The inlays are then integrated into cards using typical card-making processes such as reaction injection

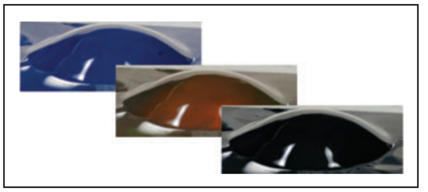

Fig. 6: These three-layer full-color electronic skins have been conformed to a spherical (complex) surface by thermoforming. The skins are fully functional and switchable.

Fig. 7: Conceptual ideas for smart-card displays integrated in consumer credit and loyalty/membership cards include both segmented and graphical displays.

molding, lamination, *etc.* It is expected that mass-market realization of high-information-content displays in cards will take place in 2012 and beyond.

Competitive Landscape

Approaching unconventional applications in displays requires an understanding of a new competitive landscape and field. Traditional competitors have included other bistable displays, conventional TFT-LCDs, *etc.* Now, the competitive technologies are white boards, pen and paper, magnetic writing toys, *etc.* for writing tablets. For electronic skins, the competitors are plastic housings, cases for mobile devices, replaceable fixed color skins, *etc.* Although there have been publications from other organizations[6] that discuss electronic skins since the first publications from Kent Displays, there have been no commercial manifestations of color-changing skins in the market thus far. For smart-card displays, certainly other display technologies are well suited (such as electrophoretic technology from E Ink and SiPix Imaging). However, key competition comes from other security applications such as those based on mobile-phone authentication. Much of this competition and positioning will really be decided by the marketplace. For writing tablets, the initial success and market acceptance of the Boogie Board is an example of validation, adoption, and demand from consumers. It was difficult to predict before the product's success, but easier to explain and justify once the Boogie Board was accepted in the marketplace. 2011 and beyond will demonstrate flexible displays emerging in new and with unconventional applications.

The Path Ahead

The path forward is hard to predict because new, unconventional display applications attract new markets that are largely unknown. A lesson learned from the Boogie Board is that one must find and exploit applications that are best suited for the technology. Flexible displays, in general, will require many new and innovative ideas. Often original equipment manufacturers are not set up to quickly make use of new transformational concepts in display technologies. There are numerous examples of organizations going beyond display manufacturing to incorporate flexible materials in products. These have included Plastic Logic with e-Readers; Polymer Vision with mobile devices with fold-out displays; E Ink with flexible demonstrators, watches, *etc.*; and Kent Displays with the Boogie Board, electronic skins, *etc.* These organizations have had to innovate and make products that are designed specifically to make use of the key features of their respective display technologies and its attributes. Following an increase in such product introductions, we will invariably see OEMs making and developing products that use such components. It is then that the flexible display segment will explode on the consumer products arena. It is anyone's guess as to when this will take place – next year, or years from now. What is certain is that it will happen.

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A Flexible Display Enables a New Intuitive User Interface

The authors developed a prototype for a flexible-display system integrated with a bend-input function that enables users to interact with the display by flexing it. The display enables users to feel as if they are operating objects on the screen directly with their hands. This interactive intuitive interface is suitable for simple operations in application software and opens up new possibilities for flexible displays to be used as user-interface devices.

by Hajime Yamaguchi, Tsuyoshi Hioki, Shuichi Uchikoga, and Isao Amemiya

FLEXIBILITY is generally considered an important part of the future of displays. In recent years, a great deal of effort has gone into developing suitable modes and manufacturing methods for flexible displays. Reflective and self-emissive modes such as electrophoretic[1,2] and organic light-emitting diodes (OLEDs)[3,4] have often been used for implementing flexible displays. But what is the actual potential value of flexibility?

Thinness and lightness are obvious positive attributes that also relate to the portability for mobile use. The ability to create a curved display through a flexible medium is also of value for design [Fig. 1(a)]. However, we suggest that input functionality through bending should be added to the potential value of flexible displays. Such functionality has three features – integrated input/output (I/O), analog input, and three dimensionality – that compares favorably to those of conventional pointing devices as shown in Fig. 1(b). The interactive operation of objects is achieved through the integrated I/O. Continuous changes in the radius of curvature of flexible displays enable analog input. And three-dimensional input means operation of the out-of-plane axis (z) of displays is possible compared to that of two-dimensional input operation of the in-plane axes (x,y). The addition of these features makes flexible displays into intuitive user-interface devices, not just display devices.

Concepts for input functions using bending have been presented in the past. But the bended parts were not displays but plastic plates or other materials attached to conven-

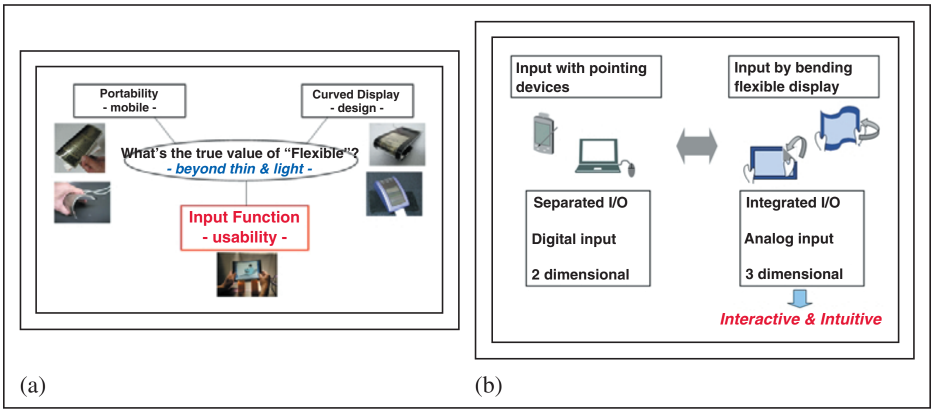

Fig. 1: (a) Some well-known values of flexible displays include portability and the capability of being made into a curved design. Input functions add usability. (b) Input functions with pointing devices (left) involve a separated I/O, digital input, and two dimensions compared to a more intuitive interface for flexible displays that incorporates integrated I/O, analog input, and three dimensions.

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tional displays. One such concept is Gummi,[5] a bendable computer proposed by C. Schwesig *et al.* (Sony CSL, Japan) in 2003. Some interesting works were also reported in 2008 when J. Scott *et al.* (Microsoft Research Cambridge, UK) fabricated a force-sensing prototype using an augmented Ultra Mobile Personal Computer (UMPC).[6] An intuitive page-turning interface for e-books[7] was presented by T. Tajika *et al.* (Osaka University, Japan). And G. Herkenrath *et al.* (RWTH Aachen University, Germany) proposed twisting and bending in mobile devices.[8]

However, we created a prototype for a flexible-display system that is actually integrated with the bend-input function. We have been able to demonstrate zooming in/out in Google Earth and page up/down functionality in PDF files by bending the flexible display. The interface of the prototype is interactive and suitable for basic operations of applications software.

Methods

We used an 8.4-in. SVGA TFT-LCD, which has thin glass substrates (less than 0.1 mm in thickness) as a flexible panel.[9] For convenience, thin glass substrates were used in developing our prototype, although flexible displays based on plastic substrates have also been developed.[10,11] The panel is sandwiched between two polarization films. We also developed a flexible backlight unit that consists of a thin light-guide plate (0.4 mm in thickness), 24 LED chips, and optical films including reflection, diffusion, and prism sheets. A flexible bending sensor, which is a commercially available resistive type, was augmented so that it could detect both convex and concave bending. The bending sensor was then attached to the flexible backlight unit. The interface between the bending sensor and the PC was accomplished using an microprocessing unit (MPU) and an AD converter. A firmware program for the MPU was developed so that the flexible backlight unit with a bending sensor was recognized as an human interface device (HID) by Windows.

Flexible Backlight Unit with a Bending Sensor

Figure 2 (left) shows a photograph of our developed unit. Bending the flexible backlight leads to changes in resistance of the sensor. The amount of change depends on the radius curvature of the display. Convex and concave bending increases and decreases the resistance, respectively. So, the unit can detect both the amount and the direction (convex and concave) of bending simultaneously as shown in Fig. 2 (right). The radius of curvature of the flexible backlight unit reaches 50 mm.

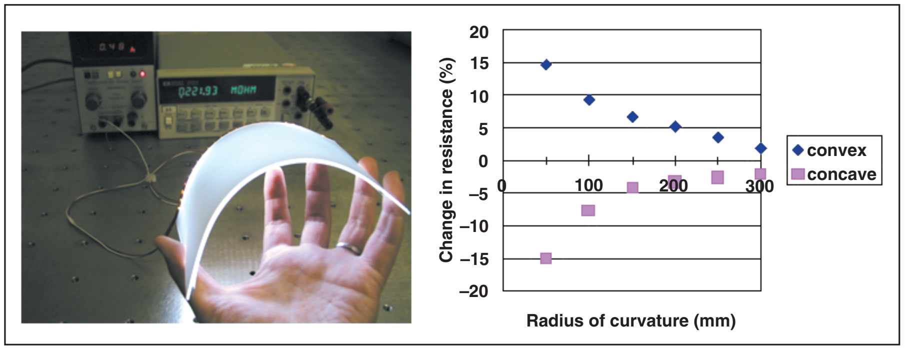
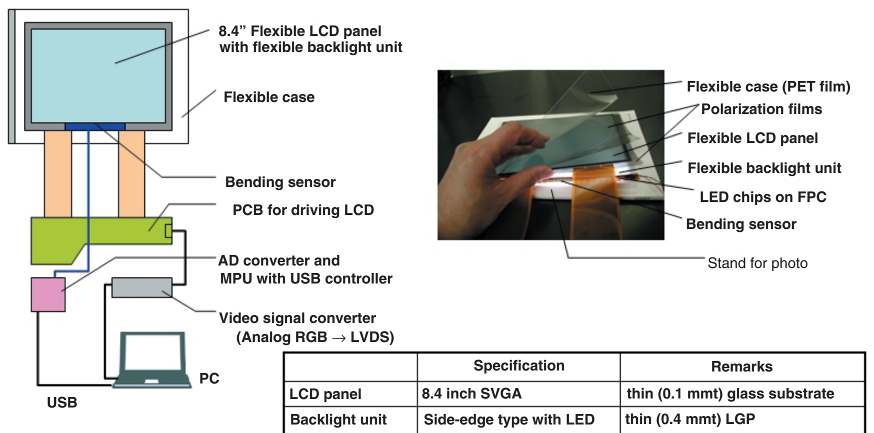


Fig. 2: The developed flexible backlight unit with a bending sensor is shown on the left On the right, changes appear in the resistance of the bending sensor with regard to the radius of curvature of the backlight unit.

Flexible-Display System

Figure 3 shows schematics and a photograph of the system, as well as specifications for a flexible-display system with bend-based input function.

The flexible LCD panel, the backlight unit with the bending sensor, and the polarization films are enclosed in a flexible case so they can be bended as one. Resistance of the sensor is digitized by the AD converter and compared with that of the flat state of the sensor, or the flexible display, in real time by the MPU. The threshold value of the radius of curvature for the operation of application software is programmed into the firmware of the MPU, and the resistance of the bending sensor is affected by ambient temperature and usage



	Specification	Remarks
LCD panel	8.4 inch SVGA	thin (0.1 mmt) glass substrate
Backlight unit	Side-edge type with LED	thin (0.4 mmt) LGP
Bending sensor	Resistive type	adapted for sensing both convex and concave
AD converter	MCP3208 (Microchip)	12 bit
MPU with USB controller	CY7C680 13A (Cypress)	EZ-USB FX2

Fig. 3: A schematic of the entire system appears on the left, with details of the display and bending sensor in the photograph on the upper right. On the bottom are the specifications for the flexible-display system.

history. A reset button is installed so that the resistance of the bending sensor is reset to the flat state of the flexible display when the button is pressed.

Operation of Application Software with Flexible-Display System

Our developed prototype for a flexible-display system can be bent in two directions, convex or concave. In both directions, bending states are continuously measured. Figure 4 illustrates the mapping of bending to intuitive interface operations with Google Earth and PDF files.

In the case of Google Earth, the screen can be zoomed in/out when the flexible display is bent in convex/concave state from a flat state. The zooming is stopped when the display is returned to a flat state. Customizable events triggered by the maximum level of bending can be programmed into the firmware of the MPU. Such an event might be the backlight switching off so that users stop bending the display. The speed of zooming corresponding to the radius of curvature of the display can be also set in the firmware. Figure 5 shows continuous zooming of Google Earth by bending the flexible display.

For the operation of a PDF file, the bending sensor is installed at the rear side of backlight unit near the corner. Page up/down is achieved by bending the corner of the flexible display in the concave/convex state. The screen view is retained when the display is returned to a flat state. The speed of paging in correspondence to the radius of the curvature of the display can be also set in the firmware. Users can therefore read PDF files and e-books in a manner similar to printed media.

This input-output integrated system enables users to feel as if they are operating objects on the screen with their hands. Analog characteristics can be realized with continuous changes in the radius of curvature of the flexible display. These features make flexible displays into intuitive user-interface devices, not just display devices.

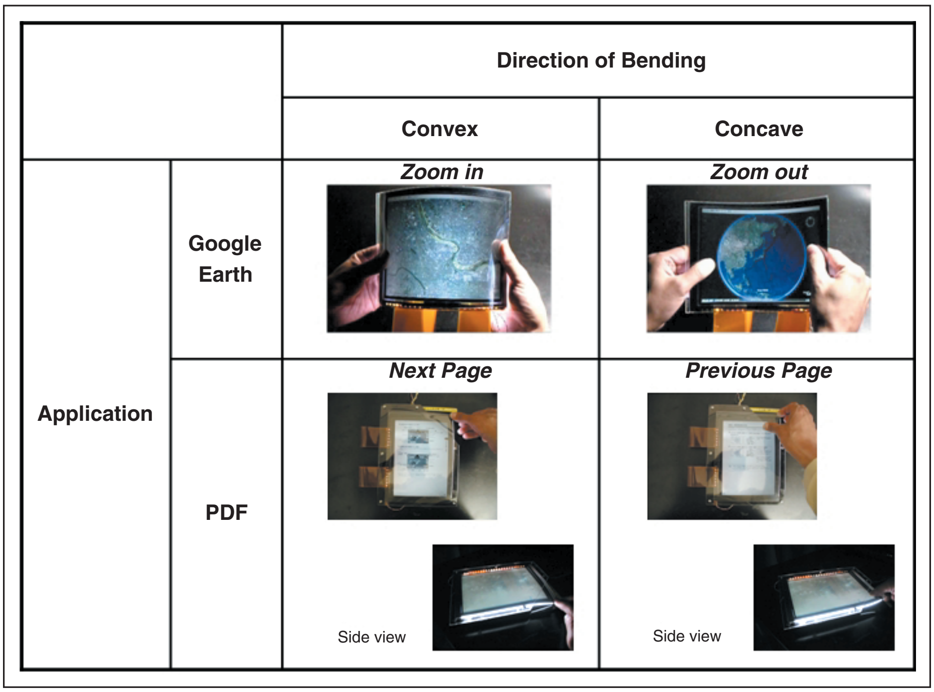


Fig. 4: Bending can be mapped to intuitive interface operations in order to, for example, (top) zoom into the topography in an application such as Google Earth and (bottom) move forward and backward through pages of a PDF.

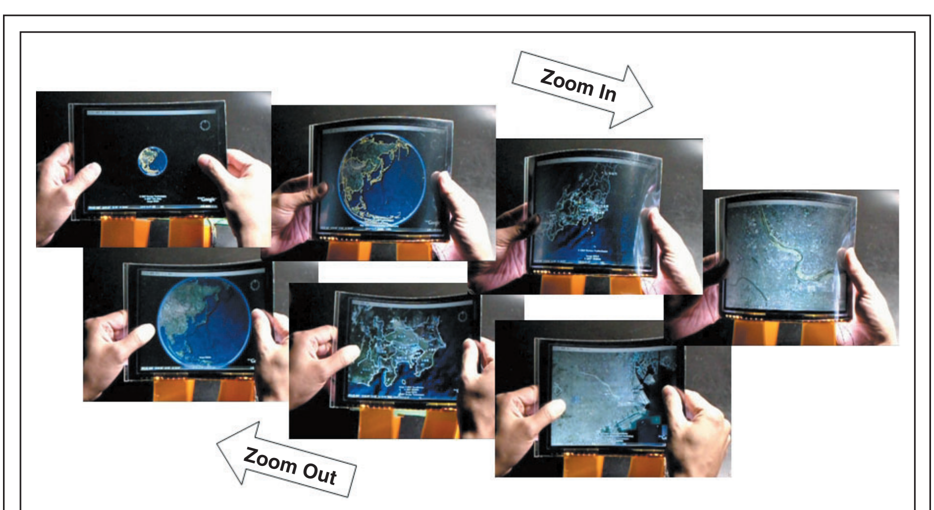


Fig. 5: Continuous zooming in Google Earth can be accomplished by bending the flexible display. Convex (top) zooms in and concave (bottom) zooms out.

Flexible Displays in Cloud Computing

Even if a display is flexible, information devices, which have processing and storage functions, cannot be flexible. How might flexible displays still be useful in this context? In recent years, cloud computing, in which processing and storage functions remain on the network while being accessed remotely, has been changing the computing world. Previously, we developed a separate system[12] that uses a flat conventional (non-flexible) display and exhibited it as a detachable display at CeBIT 2005 and International CES 2006.[13] In this system, a user needs only a handheld interface, wirelessly connected to the network. Such a device could be a flexible display with an integrated input/output function and, as such, makes a promising candidate for a cloud computing user interface.

New Possibilities

The authors' prototype of a flexible-display system integrated with a bend-input function consists of a flexible display, flexible backlight unit with bending sensor, and MPU connected to a PC. Zooming in/out in Google Earth and page up/down in PDF files have been successfully executed by bending the flexible display. The interface of this prototype is interactive and suitable for the simple operation of application software. It opens up new possibilities for flexible displays as intuitive user-interface devices.

Some of these possibilities include a tablet-like display that could be manipulated in new ways or other types of mobile devices that would allow users to zoom in and out of maps, floor plans, *etc*. Intuitive page turning for e-readers might be another possibility. That is the case for web-browsing, in which users are allowed to easily move backward and forward through web pages. Another example is moving through layers in CAD or graphics, which have the layer structure. And, as with many new display technologies, the interface's very existence may drive new applications as yet unthought of.

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Flexible Displays: Still a Lot to Learn

The development of full-color video-capable flexible displays is well into its second decade. In order to bring products to market (and end-market requirements are not yet clear), display developers need to surmount several technology hurdles. Recent demonstrations show the diversity of approaches being used to create truly flexible displays.

by Paul Semenza

WHILE the display industry has made many advances toward the goal of creating flexible displays, it is still deep in the process of selecting and refining the optimal combination of technologies. The three critical components are the display medium, the control mechanism, and the substrate. The display media that have been of greatest interest for flexible displays include all three of the main technologies: transmissive (LCD), emissive (OLED), and reflective (electrophoretic, as well as electrowetting, bistable reflective LCD, and cholesteric liquid crystal). Given the desirability of full-color and video capability in most applications, active-matrix backplanes are currently being used in the majority of cases, although some display types can utilize passive control. Many substrate types have been demonstrated, including various forms of plastic or acrylic materials and metal foils. These three key components impact each other; for example, high-temperature TFT processing cannot be performed on most plastics, but metal foils would preclude using transmissive liquid-crystal technology. These choices also relate to manufacturing processes, such as roll-to-roll, which in most cases are still in development.

While LCD technology increasingly dominates the display market as a whole, the fact that it normally operates in transmissive mode and [for twisted nematic (TN) and other standard modes] has a great sensitivity to the cell gap severely limits application of this dominant technology to flexible displays. However, it is possible to construct LCDs using rigid plastic, which can be lighter and more rugged than glass, but which do not allow the typical high-temperature processes used to fabricate TFT arrays on glass (Fig. 1).

One way to utilize liquid-crystal technology for flexible displays is to use other LC modes. For example, Fujitsu has demonstrated flexible LCDs using a cholesteric liquid-crystal material (Fig. 2).

Interestingly, this approach does not use active-matrix addressing; instead, it employs three passive-matrix monochrome LCDs in a stacked configuration.

The most mature medium for flexible displays is electrophoretic, which is typically made on a polyethylene terephthalate (PET) or other flexible sheet. However, the vast majority of electrophoretic products manufactured to date have been in the form of e-book readers, in which the electrophoretic material

Fig. 1: Samsung's plastic LCD uses a TFT backplane made with a low-temperature process (<220ºC). The LC cell (not including the backlight) is only 0.44 mm thick and weighs 28 grams. Source: Samsung.

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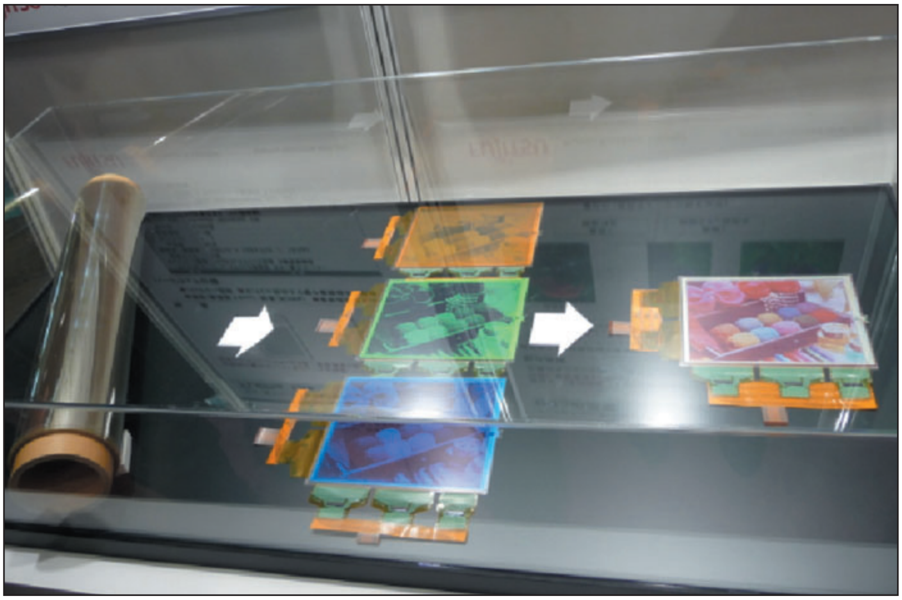

Fig. 2: Fujitsu's flexible LCD uses a cholesteric LC mixture. Source: Fujitsu.

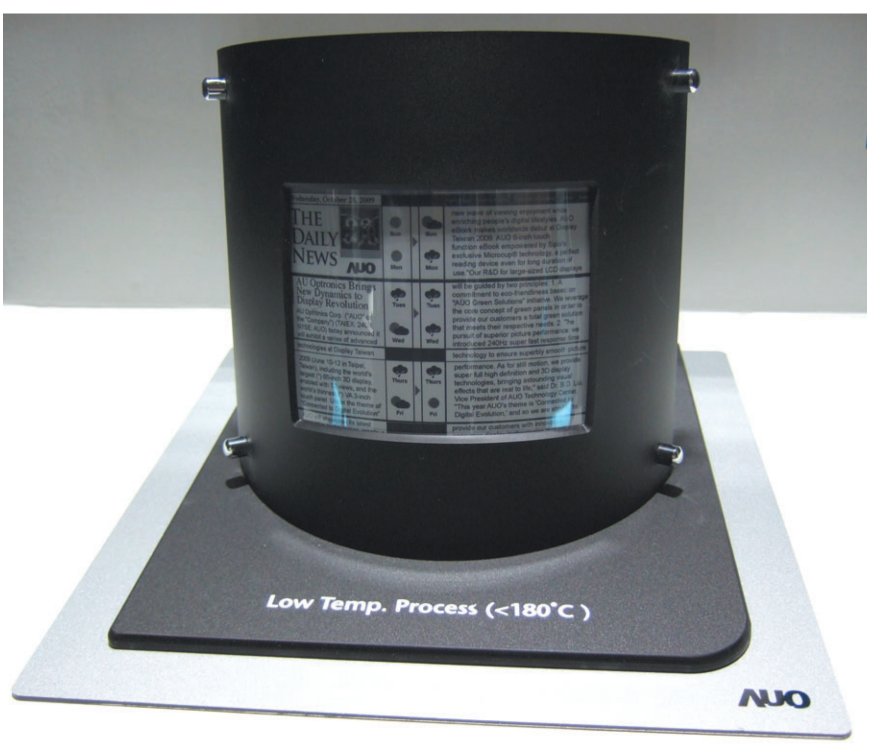

Fig. 3: AUO's flexible display uses SiPix electrophoretic material on a polyethylene naphthalate (PEN) substrate, with an oxide TFT backplane deposited through a low-temperature (<180ºC) process. Source: AUO.

Fig. 4: LG Display's 19-in. flexible electrophoretic display uses a metal backplane. Source: LG Display.

is attached to a glass substrate containing the TFT array. The crucial technology here will be in the backplane. Electrophoretic developers E Ink and AUO/SiPix have demonstrated flexible versions of their technologies using plastic substrates (Fig. 3), while others, such as LG Display, have built flexible electrophoretic displays using metal backplanes (Fig. 4).

Several other reflective display technologies have been demonstrated or proposed for flexible displays, including electrochromic (which to date has only been implemented in simple segmented forms) and electrowetting.

One of the areas of greatest interest for flexible displays is OLED technology. OLEDs have several attractive characteristics for flexible implementation, including full-color emissive operation (meaning no external lighting is required) and an inherently thin form factor with the potential for fabrication on a single substrate (both of which simplify the mechanics of bending). The visual quality of initial flexible OLED displays is better than any flexible display technology shown to date (Fig. 5).

The key challenges for flexible OLEDs are the requirement for a current-driven active matrix on a flexible substrate and the need for high levels of encapsulation, as the organic

Fig. 5: Samsung's flexible AMOLED displays demonstrate high-quality imagery. Source: Samsung Mobile Display.

materials are susceptible to damage when exposed to oxygen and water vapor. The substrate must be able to withstand the high temperatures of the TFT manufacturing processes, which can be over 400ºC for low-temperature polysilicon (LTPS) TFTs; research is ongoing with regard to the use of a-Si TFTs, as well as oxide and organic TFTs, but thus far these approaches do not appear to provide the required electron mobility. Polyimide film, while stable at high temperature, is typically yellowish. Taiwan's Industrial Technology Research Institute (ITRI) has demonstrated flexible AMOLEDs built on a polyimide film that is transparent and colorless, and also includes silica particles, increasing its temperature range. For more about this technology, see the article, "A Flexible Universal Plane for Displays," in this issue.

At the same time, ITRI has developed a bond/de-bond process using a polymer that is adhesive to a glass substrate that is used to hold the film during the deposition process, but not to the polyimide film itself, facilitating easy de-bonding. Another approach to the challenge of a flexible TFT backplane is to use organic materials for the TFT, which can be printed or deposited at low temperatures, allowing the use of plastic substrates (Fig. 6).

Other types of flexible emissive displays are also possible. Inorganic electroluminescent displays have been made in flexible forms, typically in low-information-content versions for clothing or other decorative uses. Inorganic LEDs can be strung or woven together to form a flexible sheet, but are inherently low resolution. By using individual tubes, plasma displays have been made in configurations that are flexible in one dimension.

The long-run potential for flexible displays is tremendous; DisplaySearch forecasts that by 2018, flexible-display revenues will exceed $8 billion, 100 times 2008 revenues. This includes flexible displays built on plastic, metal foil, or even ultra-thin glass, but does not include "formed" displays that are in a non-planar but inflexible form. Such displays could occupy a middle ground between flat and flexible displays, in applications where the display shape needs to conform with the overall system – for example, automobile dashboards – or to make a design statement, such as the contoured display in the Google Nexus S phone.

How to make flexible displays is one challenge, but the ultimate question about this technology – how it will be implemented – has drawn a great amount of speculation and conceptual thinking, from ideas for displays that roll up into a pen to those that fold up like a map. However, as with any significant innovation, these ideas may be too ambitious in the near term as well as too limiting in the long term. The reality is a sort of chicken-and-egg situation: flexible displays need to be built and commercialized in order for the industry to really understand their value and potential. Through the development of products using flexible displays, manufacturers will understand the operating requirements. Until then, it is not clear what matters most about flexible displays. While the goal may be the ability to operate in a curved form factor, or to bend actively during operation, other factors, such as light weight and the ability to operate in rugged settings, may be equally important. Flexible display developers will have to continue to search for the ideal combination of technologies in order to continue that learning process. ■

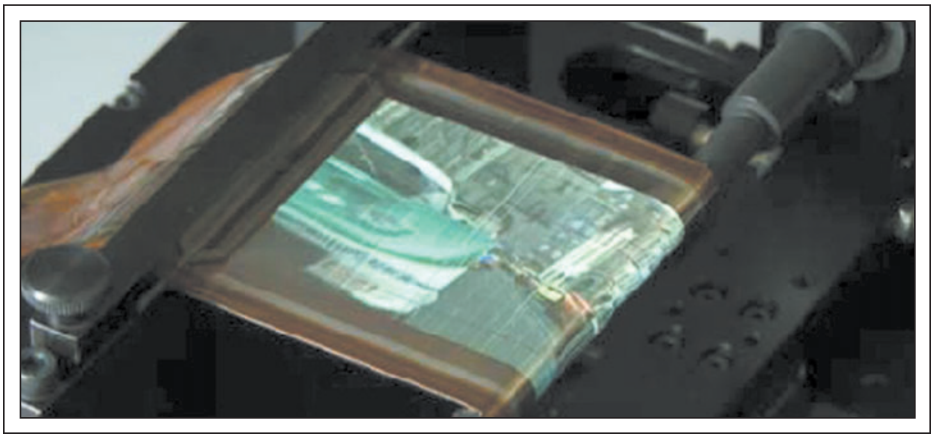

Fig. 6: Sony's rollable OLED uses an organic TFT. Source: Sony.

Display Week 2011

Los Angeles Convention Center
Los Angeles, California, U.S.A.
May 15–20, 2011

SID is ready for its close-up! Home to Hollywood, Los Angeles is the epicenter of the television and motion-picture industry. The recent advancements in 3-D technology make LA the perfect host for the 2011 SID International Symposium, Seminar & Exhibition. Display Week will be held May 15–20 at the Los Angeles Convention Center, with the exhibition open from May 17–19.

Display Week is the once-a-year can't-miss event for the electronic-information-display industry. The exhibition is the premier showcase for global information-display companies and researchers to unveil cutting-edge developments in display technology. More display innovations are introduced year after year at Display Week than at any other display event in the world. Display Week is where the world got its first look at technologies that have shaped the display industry into what it is today; that is, liquid-crystal-display (LCD) technology, plasma-display-panel (PDP) technology, organic light-emitting-diode (OLED) technology, and high-definition TV, just to name a few. Display Week is also where emerging industry trends such as 3-D, touch and interfaces, flexible and e-paper displays, solid-state lighting, digital signage, and plastic electronics are brought to the forefront of the display industry.

Watch the Stars Shine

CES 2011: The Consumer Side of Displays

Information Display checks out the show floor at the 2011 Consumer Electronics Show in Las Vegas.

by Alfred Poor

THE Society for Information Display's annual "Display Week" conference is the must-see event for the display industry. With its international attendance, non-stop multi-track programming, and packed exhibit hall, it's a one-stop opportunity for designers and engineers to see the latest in display technology. If you want to see what those designers and engineers create with these amazing components, you need to attend the annual Consumer Electronics Show (CES), held each January in Las Vegas, Nevada, where the retailers get to see the finished products and place their orders for the coming year.

It is important to keep in mind that Display Week and CES are quite different in one key respect: Display Week is a technology show and CES is an applications show. Display Week exhibitors generally present products and processes intended to be incorporated into end products for business and consumers. CES is all about those end products, from automotive electronics to mobile phones, from portable computers to enormous televisions. And just about everywhere you may wander among the 2 million square feet of exhibit space, you will see displays in all these products -- thousands of them. This article provides an overview of some of the display stories that developed at this year's CES 2011.

Alfred Poor is an editor and publisher of the HDTV Almanac *and a freelance writer covering technology topics with special emphasis on displays. He can be reached at apoor@verizon.net.*

3-D TV Is Still Hot

The big display story has to be stereoscopic 3-D television. All major manufacturers – and some lesser brands – offer some 3-D TV models. The vast majority rely on the use of shutter glasses, which are synchronized to the display. These active glasses have the advantage of delivering the full-screen resolution to both eyes, and this approach can be implemented on just about any high-definition display that can handle a refresh rate of 120 Hz or greater. The downside is that the glasses are expensive and, to date, they have been relatively heavy and unattractive compared with the slimmer passive glasses that consumers wear when they see a 3-D movie at their local cinema.

Most of the 3-D-ready displays were based on LCD flat panels, though many manufacturers – notably Panasonic – also have plasma flat-panel models. Mitsubishi also continues to make 3-D-ready rear-projection displays that offer very large screens at aggressively low prices.

Panasonic had a giant array of 3-D plasma-panel displays on exhibit, where the monster 152-in. plasma panel in the center dwarfed the other big screens that surrounded it. Images courtesy Alfred Poor.

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The big news that broke days before CES 2011 was that Vizio is shipping a 65-in. 3-D TV that relies on passive glasses. Vizio's set uses a patterned retarder added to the LCD panel so that the polarization changes with alternate horizontal lines of pixels. The advantage is that the glasses are simpler to make and cost less; Vizio will be including four pairs with each set. On the down side, this approach cuts the resolution seen by each eye in half. By itself, the passive glasses design is not a big deal. However, the passive-glasses approach requires an additional layer of material in the display panel, and this should presumably add to the materials and processing costs for the set. Despite this, Vizio has announced that the set is priced at $3499, which is as much as $1000 less than an equivalent set from a competing major brand that relies on active glasses.

It was not surprising that LG also exhibited a passive-glasses set, as LG is the source of the panel used by Vizio for its model. If the passive-glasses approach can be sold for a price equal to or less than the active-glasses models, then I expect that consumers will flock to the new approach and it will rapidly gain market share.

The third approach to 3-D TV is an autostereoscopic display, and there were plenty examples of these to be found around CES. A number of companies are exploring autostereoscopic displays for small handheld devices, including mobile phones and portable video-game players. Perhaps one of the most intriguing involved a technology demonstration by Toshiba, which showed a laptop computer with a steerable autostereoscopic LCD panel, with the head-tracking for a single user controlled by face-recognition software. The result was very effective.

Less effective, however, were the large autostereoscopic panels demonstrated by Sony, LG, and Toshiba. Not only did these noticeably reduce the effective resolution of the displays, but you are limited to fixed "sweet spots" in front of the screens where you could see a coherent stereoscopic image. The multiple views come at the price of lower image resolution. (Sony did have a demonstration using a 56-in. 4k-resolution panel that had noticeably better detail in the image.) None of the companies demonstrating these multiviewer sets announced any plans to commercialize the products, and it is not clear that there will be a commercially viable solution for living-room applications any time soon.

OLEDs Remain a Novelty

As in recent years, there were prototypes of larger OLED displays in evidence at several booths, and many were showing 3-D content (using active glasses). LG showed 15- and 31-in. models, and Hisense had a 15-in. 2-D model in its booth. The difference between this year and prior years is that nobody was talking about ship dates or retail prices. LG is on the record saying that it has plans to introduce a 31-in. OLED 3-D TV in the near future, but that's about as specific as anyone would get.

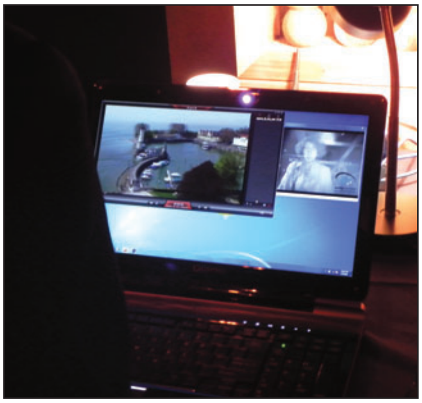
Based on what was shown at CES this year, OLED technology continues to make sense for high-end portable devices that require high-quality screens. It does not look as though a competitively priced OLED television is going to hit the shelves any time soon, however.

Projecting a Brighter Image

CES has not been known as much of a show for projectors in the past, but that is changing rapidly. Home-theater projectors continue to come down in price, making a front projector practical as an alternative to a large flat-panel HDTV. For example, BenQ showed a 1080p projector that sells for under $1200. As with the flat panels, however, 3-D is an important part of the story for front projection, with Sony offering a new model for under $10,000 and Mitsubishi showing a new 1080p SXRD LCoS model that uses active glasses and sells for under $7000.

There were many more projectors in evidence at CES 2011 than these home projectors (and the familiar business and education projectors). The pico-projectors have landed in force, and in addition to all the stand-alone devices that we have seen from companies such as 3M, Microvision, and LG, there were more products than ever that had these tiny projectors embedded in them. For example, the Cinemin Slice from Wowee is an iPad dock that has speakers and a DLP pico-projector built-in. It is only rated at 11 lm, so you will have to dim the lights, but it makes it easy to share photos and videos without having to crowd around the tablet's small panel.

Sony showed two new video cameras that have embedded pico-projectors. Imager-manufacturer Syndiant showed a number of applications for pico-projectors, including a prototype of a portable wireless media player with an embedded projector. Some



Toshiba demonstrated a notebook computer with an autostereoscopic display that relied on head tracking to steer the images to the viewer. The window on the right shows the facial recognition software used by the head-tracking system.

companies are exploring the design of a pico-projector with a television tuner to be used as a low-cost battery-powered television set for developing markets in China and India.

Displays to Go

Everywhere you looked at CES 2011 there were displays on exhibit. There were big ones and tiny ones, but perhaps most visible of all were the smaller ones. In addition to the usual flood of new mobile phones (with multi-touch displays), two new categories stepped fully into the spotlight this year: e-book readers and tablets.

The e-book readers have been coming for a while, but now it is clear that this is a viable market segment. Companies showed low-power bistable solutions, such as the popular Amazon Kindles. New low-power color models were also shown, including a prototype mirasol® display from Qualcomm. There were also readers with more conventional LCD panels, such as the NOOKcolor from Barnes & Noble, which uses an IPS panel from LG.

While there were plenty of e-book readers at the show, the hot new category was tablet PCs. The runaway success of the Apple iPad has drawn a lot of attention and, in turn, competition from other manufacturers.
The Samsung Galaxy Tab has become an overnight success, with more than 1.5 million units sold since its announcement last fall.

But the market is going to get more crowded; by some estimates there were as many as 100 new tablet products introduced at CES 2011. IDC has reported that tablet PC sales will reach 44 million units worldwide this year and will keep growing to 71 million units in 2012.

More Displays in More Places

If there's a single broad take-away point from CES 2011 (aside from the fact that it is an unimaginably large event), it is that consumer electronics are more about displays than ever before. We are going to have more devices with more displays, and these devices will be in contact with each other through local networks – wired and wireless – and the Internet so that they can share useful information beyond just photos, music, and video. It is clear that there will be demand for all manner of displays, both in terms of size and quality. And along with these displays go all the supporting materials, including solid-state light sources, substrate materials, electronics, and everything else that is required to make a functional display.

As a result, when I go to Display Week in Los Angeles this May, I will stroll through the exhibit halls with a new perspective. Not only will I be looking for new and clever display technologies and supporting components, but I will also be looking to see how they might fit into the shifting landscape of the consumer-electronics market and its apparently endless appetite for more displays. ■

LatinDisplay 2010/IDRC 2010: The Display World Comes to Brazil

by Ken Werner and Alaide P. Mammana

A technical symposium with over 23 presentations, a roundtable discussion on the impact of displays on the media, and a "display school" with courses on OLEDs, measurements, and visual perception were just a few of the many highlights of LatinDisplay 2010/IDRC 2010, the premier Latin American event for displays and related technologies. It took place at the Pontifical University of São Paulo in São Paulo, Brazil, from November 16–19, 2010. This event was combined with the International Display Research Conference and was the first time the IDRC took place in the Southern Hemisphere.

The technical sessions began with Margarida Baptista of BNDES (Brazilian Development Bank) describing the economic and social situation in Brazil, which enjoys the leading economy in Latin America. The Brazilian government is offering incentives to foreign companies to form joint ventures with Brazilian companies in order to manufacture displays in the country.

The opening session included an overview of the socio-economic situation in Brazil. At the symposium, scientists from all over the world presented the latest advances in display technologies, display manufacturing, visual perception, TV, and 3-D TV. Technologies also discussed because of their direct relationship to displays were touch screens, solar cells, lighting (fluorescent lamps, LEDs, and OLEDs), organic electronics, and batteries, including their materials, processes, and equipment. Of the 23 invited lectures, the international breakdown was as follows: three from Brazil, nine from the U.S., six from Europe, two from Japan, one from China, one from Taiwan, and one from India. In addition, there were 42 contributed papers from all over the world.

Presentation Highlights

Presentations included several lectures and papers on 3-D TV (Nutmeg Consultants, Planar Systems, KIST, and LG), describing the display R&D community's concerted efforts to improve the performance of 3-D displays. Bernard Coll, until recently of Motorola, discussed frame- and service-compatible 3-D TV formats. He suggested that video processing can be used to advance overall perceived image quality and can improve viewer comfort by avoiding image-encoding artifacts.

Digital TV and video coding (Unicamp), video-quality estimation (University of Brasilia), and moving-picture quality (LG) were also discussed at LatinDisplay. Other lectures covered electrowetting displays (Liquavista and ITRI), advances in photovoltaics (Moserbaer), new reflective displays based on photoluminescence (H-P), electroluminescent displays and new phosphors (University of Brunel), touch screens and e-ink (Multek), and the story of Pixel Qi.

Lectures on lighting included OLED lamps (Novaled and Philips), LEDs (Walsin Lihwa), and new lamp phosphors (Brunel University). Manufacturing was also addressed, with lectures from Birendra Bahadur (Rockwell Collins) on a display lamination technology and by Don Carkner (CH2M Hill) on LCD and OLED manufacturing.

Liquid-crystal displays were the focus of presentations given by Shunsuke Kobayashi (Tokyo University of Science) on LCDs doped with ferroelectric nanoparticles (he demonstrated a nice prototype), and papers on ferroelectric nanocomposites (University of Chile), blue phase (InfoVision Optoelectronics Corp. and CTI), row-to-row cholesteric LCDs (ITRI), and hexagonal and cellular structures in the nematic state (University of Córdoba). Researchers from several universities and from CTI presented papers on materials, processes, and nanotubes, while CTI also presented a new low-cost educational touch display.

Paul Gagnon, Director of North American TV Research for market research firm DisplaySearch, discussed the recovery of the flat-panel industry, but noted that revenues will probably peak in 2010, followed by a gradual decline. This is due in part to the fact that most TV sets are sold at a price of less than $500. He also revised his 3-D TV forecast for 2010, announcing that 3-D TV sets will comprise only 1.5% of all sets sold this year.

Richard Chang, founder of the Semiconductor Manufacturing International Corporation (SMIC) in Shanghai, delivered an invited lecture on how the Chinese government is attracting high-tech industries to China. His comments excited considerable interest because many members of the audience felt the Chinese model could also apply to Brazil.

LatinDisplay 2010, the premier annual display event in Latin America, was sponsored by the Brazilian government's Brazilian Development Bank (BNDES), the Ministry of S&T (MCT), the National Council for Scientific and Technological Development (CNPq), and the Brazilian Agency for Industrial Development (ABDI).

SID news

The Brazilian Association for Informatics (ABINFO) sponsored an award for "The Best Paper of LatinDisplay 2010/IDRC 2010." The winning paper covered the resolution and power-consumption benefits of four-primary-color displays, presented by Yasuhiro Yoshida from Sharp.

Exhibits, Special Meetings, and "Display School"

The exhibition was an opportunity for companies and R&D institutions to unveil cutting-edge developments for displays and related technologies by demonstrating prototypes and products. More displays and related devices have been exhibited in each succeeding year at LatinDisplay, with the exhibits attracting increasing attention from the media and the public.

The Display Escola (Display School), held November 19 on another campus of the Pontifical University, attracted about 35 attendees who came to learn more about OLEDs (course taught by Manju Rajeswaran from Kodak), measuring displays (by Adi Abileah, Planar Systems), and visual perception (Ingrid Heynderickx, Philips Research Labs and the University of Delft).

Business meetings held at the event provided a forum in which attendees could discuss trends and business opportunities in displays and related technologies in Brazil and all of Latin America. It was clear that interest in doing business in Brazil is accelerating, and Brazilians and non-Brazilians could be seen in earnest conversations during the meetings.

The roundtable discussion on the impact of displays on the media was moderated by Ken Werner of Nutmeg Consultants. This session was introduced by David Barnes (BizWitz LLC) with a lecture entitled "More Digital Revolutions." Having a non-technical roundtable was a change of pace, and it proved successful.

Details

LatinDisplay 2010/IDRC 2010 was organized by the Latin American Chapter of the Society for Information Display (SID), Associação Brasileira de Informática (ABINFO), and the Pontifícal Catholic University of São Paulo (PUC–SP). As an event of the Brazilian Network on Displays (BrDisplay), LatinDisplay 2010 is central to supporting the implementation of the Brazilian Industrial Policy [Política de Desenvolvimento Produtivo (PDP)] proposed by the Federal Government for displays and related technologies. Therefore, the event was sponsored by the Brazilian Government, with funding from BNDES (Brazilian Development Bank), MCT (Ministry of Science and Technology), ABDI (Brazilian Agency for the Industrial Development), and CNPq (National Research Council).

More details about LatinDisplay 2010/IDRC 2010 can be found at http://www.brdisplay.com.br/latindisplay. ■

__Ken Werner__ is the Principal of Nutmeg Consultants and __Alaide P. Mammana__ is the Director of the Latin American SID Chapter.

editorial

continued from page 2

strength in the core of Latin Display to help educate and evangelize displays all on its own. I think it is worth noting that a great many very talented industry veterans from the SID community volunteer their time each year to support this event and it is sure to pay dividends in years to come. The event was, in fact, sponsored by the Brazilian Government, with funding from BNDES (Brazilian Development Bank), MCT (Ministry of Science and Technology), ABDI (Brazilian Agency for the Industrial Development), and CNPq (National Research Council). I applaud the efforts of the Latin America SID chapter, as well as the forward thinking of the Brazilian government when it comes to making investments in display technology and providing a nurturing economic environment for fledgling companies.

I hope you enjoy this very flexible issue of *Information Display*. ■

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guest editorial

continued from page 4

The article by Hajime Yamaguchi, Tsuyoshi Hioki, Shuichi Uchikoga, and Isao Amemiya demonstrates a different approach, in which the flexibility of the electronic display enables a brand new type of interface. Toshiba has devised a prototype display in which display navigation is enabled by bending the display. If a bendable interface can be made intuitive and workable across multiple applications, then a flexible display can create new applications that have not yet even been imagined.

Will 2011 become the breakout year for flexible displays? Hard to tell. I can predict, though, that the innovative work showcased here, in the *Journal of the SID*, and during SID's Display Week, makes it likely that widespread adoption of flexible displays could be just around the corner.

I'll use this column to point out a major new review paper covering the current status of electronic paper, a field that overlaps greatly with flexible displays. The paper appears in the February 2011 issue of the *Journal of the SID* (*JSID* 19/2) and is entitled *"A critical review of the present and future prospects for electronic paper."* It is written by Professor Jason Heikenfeld (University of Cincinnati), Dr. Jong-Souk Yeo (most recently at Hewlett-Packard, but moving to Yonsei University), Dr. Tim Koch (Hewlett-Packard), and myself. If you have any interest at all in the field of electronic paper, please check out this article — I can guarantee you will find it worth your while. ■

__Paul Drzaic__ is Principal at Drzaic Consulting Services and has worked on flexible displays and components throughout his career. He is Past President of SID. He can be reached at drzaic.consulting@gmail.com.

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The following papers appear in the February 2011 (Vol. 19/2) issue of *JSID*.
For a preview of the papers go to sid.org/jsid.html.

Papers by Subject Categories

Active-Matrix Devices and Circuits

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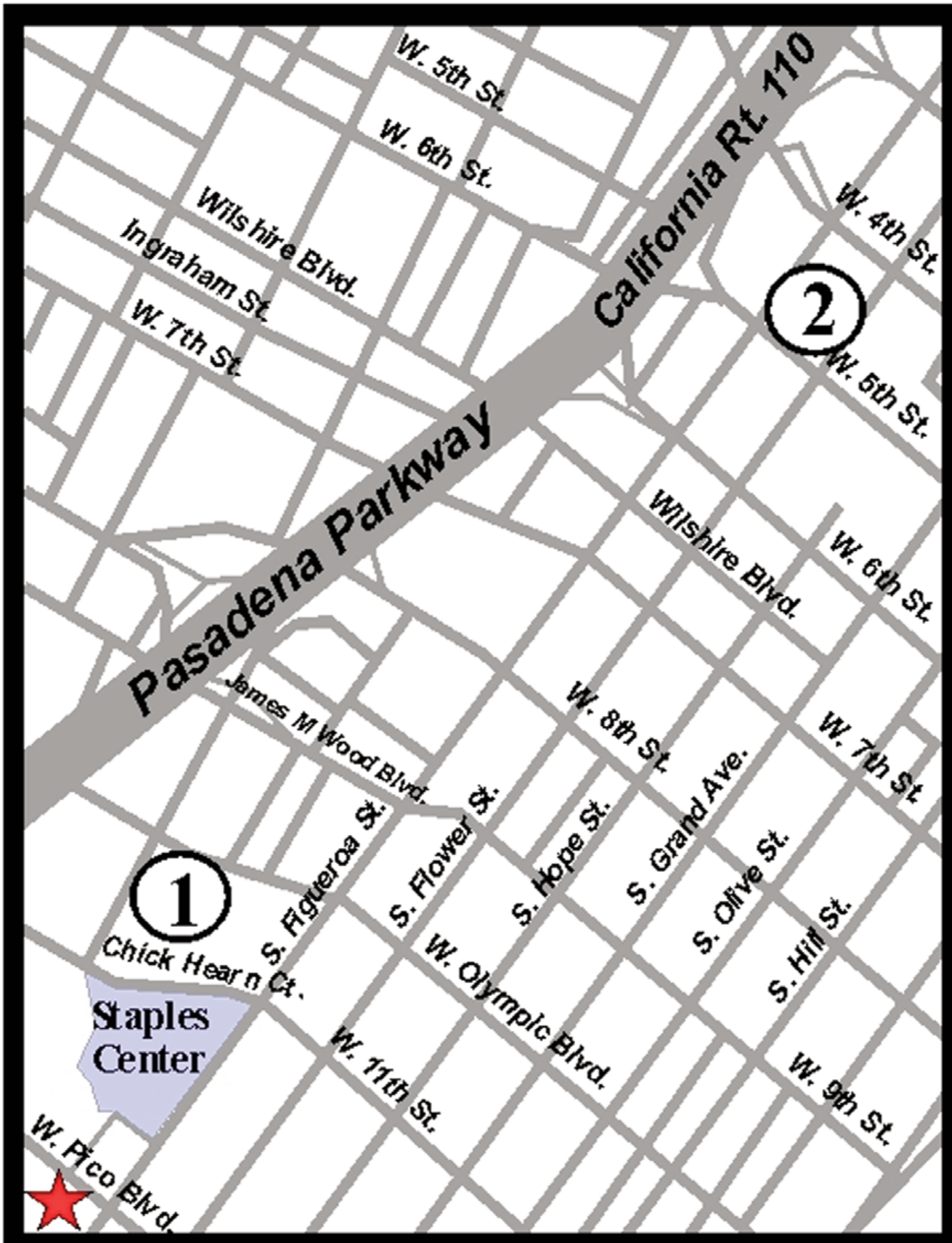

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