SID 2003 PREVIEW ISSUE

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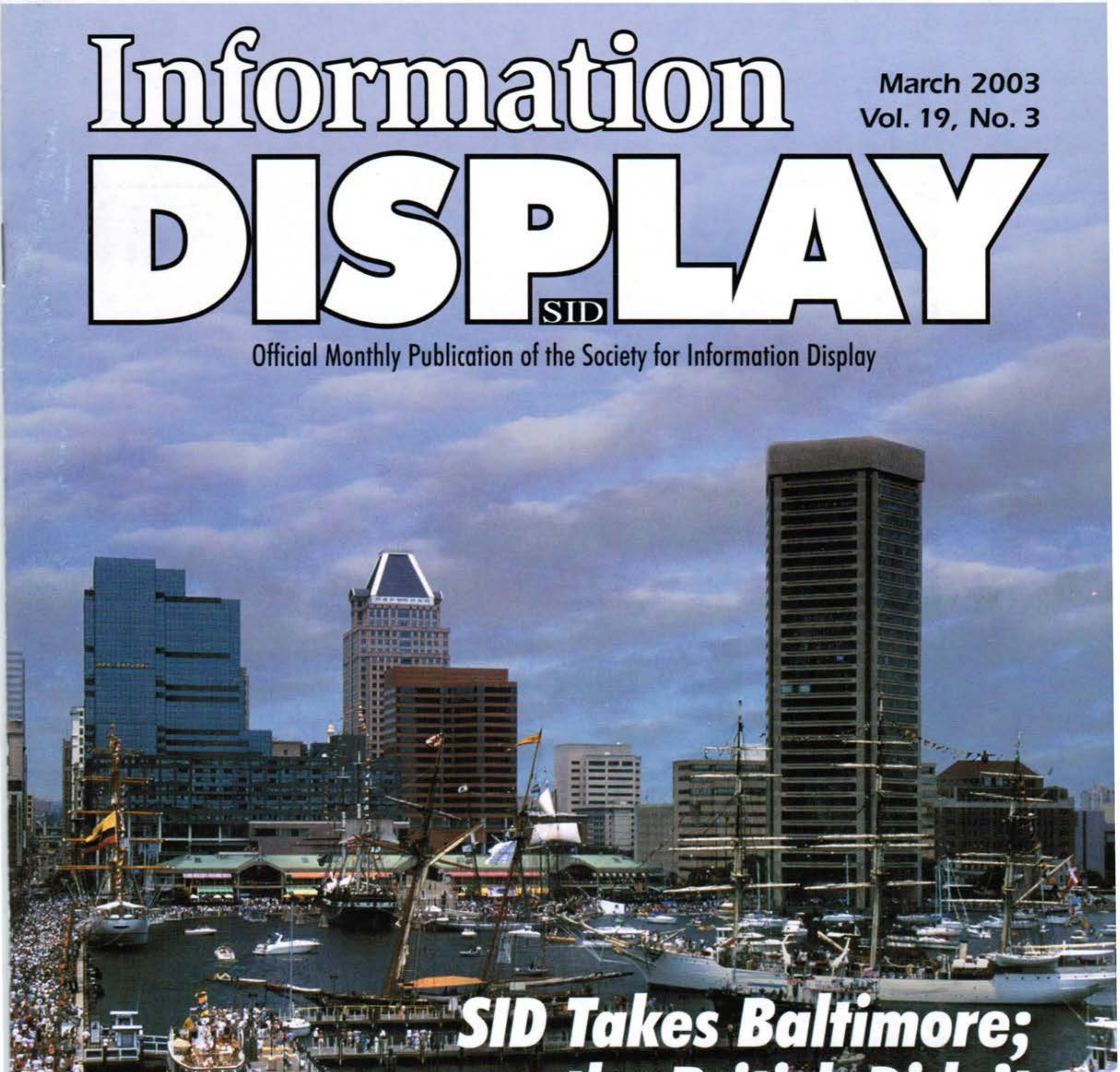

SID Takes Baltimore; the British Didn't

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SID holds its annual International Symposium, Seminar, and Exhibition in Baltimore this May. For a show preview, an introduction to Baltimore, and travel tips, see the article beginning on page 15.

For Industry News, New Products, Forthcoming Articles, and Complete, Continually Updated Conference Calendar, see www.sid.org.

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editorial

NHK Demonstrates a Phosphorescent Polymer OLED – and Then Some

An attractive offer was made to attendees at the International Display Workshops (IDW '02) in Hiroshima in early December 2002: Sign a registration form and come to Tokyo for a tour of the NHK Science and Technical Research Laboratories (STRL) on the Monday after the close of IDW.

As it turned out, it snowed on Monday – a rare December snow that surprised Tokyo residents and even delayed commuter trains, which is something in a country that takes its railroads as seriously as Japan does. As a result, only four of us showed up for the tour, but we were greeted warmly by Senior Associate Director Takayuki Ito, and the small size of the group led to a lively informality.

STRL was established in 1930, five years after the start of radio broadcasting in Japan. It is now housed in a new 14-floor 16,000-m^2 building that opened in April 2002 and houses 265 research engineers, along with support personnel. The Research Division comprises nine departments in three groups. The broadcast-related group consists of Multimedia Services, Digital Broadcasting Networks, and Digital Satellite Broadcasting Systems. The computer and information-related group consists of Advanced Audio and Video Coding, Three-Dimensional Audio-Visual Systems, and Human Science. Finally, the group related to key devices consists of Recording Technology and Mechanical Engineering, Advanced Imaging Devices, and Display and Optical Devices.

Our tour focused on five interesting pieces of hardware. The first was a simple prototype polymer-OLED display, but this was interesting because it was a phosphorescent polymer OLED. Universal Display Corp. (UDC) of Ewing, New Jersey, has done much to popularize phosphorescent OLED technology, but UDC's work has been on small-molecule materials. I had not heard of any previous work on phosphorescent polymer materials, and NHK Senior Research Scientist Shizuo Tokito agreed. Tokito said that traditional fluorescent polymer OLED materials were limited to a luminous quantum efficiency of 5%. NHK's phosphorescent green material has already reached 7.5%, he said (compared to an actual 5% for luminescent polymer materials); and the prototype red material has reached 5.5% (compared to an actual 3% for luminescent). The prototype blue phosphorescent material is currently at a 3.5% efficiency, the only material that has not yet exceeded the efficiency of the competing luminescent polymer, which stands at 4.5%. But, said Tokito, there seems to be no fundamental reason why the red material should not exceed the 5% threshold, and then some. Indeed, NHK's goal is 20% efficiency for RGB, along with fabrication of a full-color panel and a flexible display on a plastic substrate.

NHK also showed us a developmental flexible display based on a film of ferroelectric liquid crystal combined with a network of polymer fibers. The composite can be applied with simple printing techniques, said NHK's Hiroto Sato. The display also features a polymer lattice wall that separates the two plastic-film substrates and keeps the cell gap constant when the display is bent. Until recently, the flexibility of the display has been limited by the strength of the FLC–polymer-fiber composite, but a new film structure now allows the display to be bent to a 1-cm radius of curvature, said Sato (see photo).

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Information
DISPLAY

Is There Any Reason to Do Liquid-Crystal Research in the U.S.?

by John West

Today, the vast majority of flat-panel displays are manufactured in the Asian Pacific Rim. This has led some to ask if there is a role for liquid-crystal and display research in the United States. As Director of the Liquid Crystal Institute and the Center for Advanced Liquid Crystalline Optical Materials, my emphatic response is to yell Yes! Okay, I am admittedly biased. However, let me try and lay out my reasons for why I think this is a wise investment of our national research dollars.

Focusing on liquid crystals, which dominate the flat-panel display (FPD) industry, we sometimes lose sight of the fact that they are an entire phase of matter. Just because we do not lead in the manufacture of liquid-crystal displays (LCDs) is no reason to abandon the research on an entire phase of matter. Also, LCDs are far from a mature technology. Liquid crystals continue to pose interesting basic and applied research problems, and offer potential applications that reach well beyond the LCD. Clearly, we need to continue research into this important phase of matter.

Focusing on FPDs, we need to begin by recognizing that the overwhelming dominance of a handful of Asian companies in the manufacture of sophisticated LCDs is the result of their sustained commitment to the manufacture of ever-improving displays. Their vision and dogged determination have delivered a product that now, after decades of development, finally does directly challenge the cathode-ray tube (CRT).

We also need to recognize that a much larger cadre of companies, many in the United States, either provide components for the displays or incorporate them in an ever-increasing array of products. Research into the materials and technologies that support the FPD industry benefits all of these companies. For example, graduates from our programs are moving into excellent positions with companies across the nation because of their expertise and background in liquid crystals and FPDs. They are in as much – or even more – demand today than they were just a few years ago, even with the recent economic downturn. Therefore, we need to broaden our perspective from just considering where the displays are manufactured to also include the industries that (1) support the manufacturing and (2) utilize displays in consumer products.

We are fortunate to have a number of excellent research programs across the nation in academic, industrial, and federal laboratories working in the field. One of the great strengths of these programs is their ability to attract the best and brightest from around the world to join and work together. Through this research, we continue to develop the materials and technologies that will advance the display industry. We can only evaluate the return on our research investments by taking a long-term perspective.

Taking this long-term perspective, it soon becomes clear that the game isn't over; indeed, it has only just begun. I am not sure of the exact direction the new display technologies will take, but I am certain that twenty years from now the technological landscape will be totally changed. I am also sure that a strong research base will be required to play a meaningful role as we move forward.

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The SID International Symposium and Exhibition Returns to a Resurgent Baltimore

The Society for Information Display's premier conference and exhibition returns to Baltimore at a time of unprecedented expansion in the flat-panel-display market, surprising work on new technologies, and supply-chain upheavals.

by Ken Werner

THE Continental Congress met in Baltimore, and the international display community will meet there, too, in the Baltimore Convention Center, from May 18–23, for the Society for Information Display's 34th International Symposium, Seminar, and Exhibition (Fig. 1).

The annual SID Symposium has become the leading international forum for discussing and analyzing electronic-display technologies and products, as well as their underlying science, and is covered by approximately 100 technical and business journalists from around the world. It contains the largest exhibition of displays; display components; display-manufacturing equipment; display test-and-measurement equipment; display controllers, electronics, and semiconductors; backlights; display products and materials; software; services; and publications held in North America.

Display Week will kick off with half-day short courses on Sunday, May 18, and 90-minute seminars on Monday, May 19. The seminars will continue on Friday, May 23. Once something of an afterthought, the Friday schedule now contains some of the strongest seminars, and for the last 2 years has drawn high attendance.

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This year's seminars feature LCD, OLED, PDP, and microdisplay tracks, along with some stand-alone presentations. Ross Young of DisplaySearch will launch the Monday seminars with a market and technology overview. That will be followed by 12 more seminars in four simultaneous tracks, including

- ***Recent Progress in OLEDs*** by OLED co-inventor Ching Tang,
- ***LCD Television*** by H. Take, who works for LCD-TV market leader Sharp Electronics,
- ***LCD Technology*** by Gregory P. Crawford of Brown University,
- ***Plasma Displays*** by Bill Schindler of Plasmaco,

BACVA

Fig. 1: *Baltimore's appealing Inner Harbor, which is near the Baltimore Convention Center and its surrounding hotels, attracts conventioneers, tourists, and Baltimore residents.*

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Visiting Baltimore

Baltimore is a remarkable – if sometimes under-appreciated – entertainment, scientific, technological, industrial, artistic, cultural, gastronomical, and historical center (Fig. A). The city sits at the head of navigation of the Patapsco River and has one of the largest harbors in the world. The River empties into Chesapeake Bay, which in the 1890s supplied 20 million bushels of oysters to much of the United States' East Coast. Today, the Bay's signature seafood is the Blue Crab, and Maryland Crab Cakes are a "can't-miss" meal for Baltimore visitors. If hard-shell crabs are preferred whole, some casual restaurants will serve them with a wooden mallet.

Not everybody loved Baltimore. During the War of 1812, British merchant ships were set upon by the fast schooner-rigged "Baltimore Clippers" built and commissioned in the city as privateers. Britain mounted an expedition in September 1814 to root out this "nest of pirates," following its successful attack on Washington. To enter Baltimore Harbor and shell the city, the British Navy had to eliminate the batteries of Fort McHenry, which guarded the entrance to the harbor (Fig. B). But after 25 hours of bombardment, the Fort, skillfully commanded by Major George Armistead, still stood, only slightly damaged. The British ground forces had been blocked by a numerically superior American force, and could do nothing more without the support of a naval bombardment, which would now be impossible, so the British began to withdraw.

Upon taking command of Fort McHenry more than a year before, Armistead had said, "... it is my desire to have a flag so large that the British will have no difficulty in seeing it from a distance," and a 42 × 30-ft. flag with 15 stripes and 15 stars was made. As the British withdrew, Armistead raised this flag, and *Yankee Doodle* was played.

Francis Scott Key, a Georgetown attorney who had been negotiating the release of a prisoner with the British, witnessed the battle from an American ship in the harbor. When he saw the huge American flag, he was moved to quickly write down the words of the song that would soon become known as *The Star-Spangled Banner*, along with a note that the words were to be sung to the melody of a well-known English drinking song. *The Star-Spangled Banner* became the national anthem of the United States in 1931. Today, Fort McHenry is high on the list of Baltimore tourist attractions.

Baltimore had mastered the clipper, the premier transportation technology of the first half of the 19th century, and she was about to develop the next one: the railroad. The Baltimore and Ohio (B&O) Railroad, the first commercial railroad in the United States, was founded in 1827 to connect the mid-Atlantic region to the Ohio Valley – and thus provide competition for New York's Erie Canal. The man who wielded the spade at the groundbreaking to lay the ceremonial first stone was the 90-year-old Charles Carroll of Carrollton, the last surviving signer of The Declaration of Independence. He was also an early investor.

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A. The Pride of Baltimore II *is a modern wooden version of a classic "Baltimore Clipper," in Baltimore's Inner Harbor.*

The first passenger revenues were collected in January of 1830. A one-way excursion from B&O's hub at Mt. Clare to what was then the end of the line covered 1½ miles and cost 9 cents, taking 6 minutes in a horse-drawn car. In May, the first 13 miles of long-distance railroad in America were completed and the first regular railroad passenger service in the U.S. began. The ride from the new Mt. Clare Depot to Ellicott Mills took 90 minutes by horse-drawn car and cost 75 cents. The route crossed the new Carrollton Viaduct – the first stone railroad bridge in the United States, and the oldest anywhere that is still in regular use.

The first steam locomotive built in the U.S., Peter Cooper's Tom Thumb, was built at Mt. Clare and successfully tested on B&O's tracks in August of 1830, opening the age of American steam railroading. In 1835, a 40-mile branch line was built from Mt. Clare to Washington, D.C. – the first railroad to enter the nation's capital.

In 1844, Samuel F. B. Morse had his assistant Ezra Cornell – who would later establish Cornell University – string overhead wires from the basement of the Supreme Court Building in Washington along B&O's Washington branch line to the Mt. Clare Depot. On May 24th, Morse sent the famous first long-distance telegraph message – "What hath God wrought!" – from Washington. In the Mt. Clare Depot, the message was received by Cornell and Alfred Vail.

The B&O was one of the dominant forces in railroading for over a century. Mt. Clare, the place where American railroading started, is now the home of the B&O Railroad Museum, which has what is probably the most extensive collection of steam and diesel engines, rolling stock, railroad memorabilia, and telegraphy equipment in the country. The old depot where Cornell and Vail received Morse's message is part of the museum.

But that just scratches the surface of what Baltimore can offer. The former homes of Edgar Allen Poe and Babe Ruth are now museums and are open to the public. Ruth first played professional baseball for the Baltimore Orioles, then a minor league team. His home is just two blocks from Oriole Park at Camden Yards, widely regarded as the most beautiful of modern baseball parks, in part because it takes its architectural inspiration from classic ballparks of the 1920s. The Orioles will be playing home games at Camden Yards May 16–18 (against the Tampa Bay Devil Rays) at the beginning of Display Week.

Baltimore's Inner Harbor has been turned into a waterside promenade that is hugely popular with both residents and tourists. In addition to restaurants and extensive food courts, Baltimore's maritime and industrial history finds a home here. Among the attractions are

- The USS *Constellation*, the last all-sail warship built by the U.S. Navy (in 1854),
- The *Pride of Baltimore II*, a modern wooden Baltimore Clipper that follows the classic designs of the early 1800s,
- The USCGC (United States Coast Guard Cutter) *Taney*, the last surviving warship that fought during the attack on Pearl Harbor, December 7, 1941,
- The harbor inspection tug *Baltimore*, built in 1906, is the oldest operating steam-powered coal-fired tugboat in the United States,
- The USS *Torsk*, the submarine that accounted for the last ship sunk in World War II; 17 years later she participated in the blockade of Cuba during the Cuban Missile Crisis.

For those who appreciate interesting and significant architecture, Baltimore has an unfair share of it, including the Old Roman Catholic Cathedral – the oldest Catholic cathedral in the U.S. – designed by Benjamin Henry Latrobe, who also designed the U.S. Capitol. The cathedral, not the Capitol Building, is considered his masterpiece.

Don't forget to visit the Fells Point Historic District. More than 800 ships were built at Fells Point shipyards between 1784 and 1821, including the original Constellation in 1797 and many Baltimore Clippers. Seamen and sailmakers lived in the many small two-story houses, which are rapidly being gentrified. Any worthwhile harbor settlement is well supplied with eating and drinking establishments, and this tradition is carried on at Fells Point with enthusiasm.

The Walters Art Museum has an extensive collection; it encourages one to come and experience 55 centuries of art. Among its collections are 1000 pieces of Asian art, including the oldest surviving wooden image of the Buddha.

If there's time for wandering, visit the charming small city of Annapolis. In addition to being a maritime community, the home of the U.S. Naval Academy, and a bastion of small antique shops, it is the capital of Maryland.

The Eastern Shore is that part of Maryland on the eastern side of Chesapeake Bay, a relatively easygoing place devoted to farming, fishing, and summer homes. It is also where "oysters" is pronounced "arsters." There should be good fishing and sailing on the Chesapeake in May and plenty of Marylanders happy to charter or rent boats to display people who are ready to relax after Display Week.

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B. Fort McHenry saved Baltimore from sharing the fate of Washington, D.C. in the War of 1812.

Getting to Baltimore

Baltimore is served by three airports: Baltimore-Washington International (BWI); Reagan National Airport (DCA), just across the Potomac River from downtown Washington, D.C.; and Dulles International Airport (IAD), which is out in the Virginia countryside very far from any place that anybody would want to go, but it is the region's primary airport for international flights.

American railroads are not generally impressive by European and Japanese standards, but Amtrak's new Acela trains – which connect Washington, Baltimore, Philadelphia, New York, and Boston – are quite good. If you are visiting New York or Philadelphia prior to Display Week, you might want to consider taking Amtrak directly to Baltimore's handsomely renovated Penn Station, which is a short taxi ride (10 minutes, $7.00) from the Convention Center, the Inner Harbor, and the surrounding hotels.

If you are flying directly into the Baltimore-Washington area, try to fly into BWI. The other alternatives are painful, as you will see. If you do fly into BWI, the recommended way to get to the downtown hotels is by the Super Shuttle. The ride is $11.00 ($18.00 round trip) and takes 10–15 minutes. When you land, follow the ground transportation signs and make your arrangements at the Super Shuttle desk.

If you fly into Reagan National Airport, you can take the Super Shuttle to BWI. The trip takes about 45 minutes and costs $37.00, but additional passengers from the same flight are charged only $10.00 each. You then take the Super Shuttle from BWI to downtown Baltimore as described above. (There is no direct Super Shuttle service from Reagan National – or Dulles International – to downtown Baltimore.)

Alternatively, you can take the Washington Metro (subway) Yellow Line from the station at the airport (which is reached by the airport shuttle bus) toward downtown Washington, and transfer to the Red Line at Gallery Place. Take the Red Line two stops (in the direction of Glenmont) to Washington's Union Station. The fare will be less than $3.25. (The ticket machines may not take bills larger than $5.00, so have some small bills available.) The hours of operation are from 5:30 a.m. (8:00 a.m. weekends) to approximately midnight (2:00 a.m. on Fridays and Saturdays), but closing time may be as much as half an hour earlier at some stations. From Washington Union Station, take the Penn Line of the MARC commuter train to Baltimore's Penn Station ($5.75); then take a taxi as described above. MARC trains leave Union Station for Baltimore from about 6:30 a.m. to about 10:30 p.m. Monday through Friday. (There is no week-end service.) The trip takes a little less than an hour.

From Dulles International Airport, you could take a taxi (about $50.00) or airport bus into Washington, make your way to Union Station, and proceed as above, but this is not recommended because Washington area traffic is among the worst in the United States. (In an attempt to reduce congestion, government offices have staggered their working hours, but this has just had the effect of creating a morning rush hour that extends from 5:00 a.m. to 10:00 a.m. and an evening rush hour that extends from 2:00 p.m. to 8:00 p.m.!) To avoid this traffic as much as possible, simply take the Super Shuttle from Dulles to BWI ($75.00 one way, only $10.00 for additional passengers from the same flight for a trip that takes 1½ hours or more). Then take a Super Shuttle from BWI to downtown Baltimore.

Clearly, the easiest option by far is to fly into BWI. SID attendees flying in from Asia or the U.S. West Coast might want to consider flying into Chicago and connecting to a flight from Chicago to BWI.

- ***Microdisplay Design and Technology*** by Ian Underwood of MicroEmissive Displays, Ltd.,
- ***Polymer OLEDs*** by Jeremy Burroughes of CDT, Ltd.,
- ***Display Electronics*** by Nikhil Balram of National Semiconductor Corp.,
- ***Measurements and Metrics in FPDs*** by Ed Kelley of NIST,
- ***OLED Manufacturing Technology*** by G. Rajeswaran of Eastman Kodak Co.

There will also be seminars on plasma-display manufacturing and LCD manufacturing, as well as one providing an overview of microdisplays.

On Friday morning, there will be six seminars in three parallel tracks. These will include Backlighting by Munisamy Anandan of Semluz Technologies and Reflective LCDs by Shin-Tson Wu of the University of Central Florida. There will be additional Friday Seminars on OLED addressing, STN-LCDs, and Color in FPDs, as well as one overviewing a resurgent FED technology.

A rich program of vendor exhibits, application tutorials, and up to six tracks of technical-paper sessions will all be held from Tuesday, May 20, to Thursday, May 22. The technical sessions will be anchored by more than 25 invited papers. Among them are

- ***Large-Area AMLCD TV Using IPS Mode*** by S. D. Yeo of LG.Philips LCD,
- ***Pixel-Level Multiplexing*** by Manabu Kodate of IBM Japan,
- ***Manufacturing Issues in PVA TFT-LCDs for Monitors and TVs*** by Kyeong Hyeon Kim, Samsung Electronics,
- ***Evaluating PDP Image Quality*** by Taiichirou Kurita of NHK Science & Technical Research Laboratories,
- ***Overview of Bistable Liquid-Crystal Technologies*** by Ivan Dozov of Nemoptic,
- ***Basic Studies of OLED Stability*** by Denis Kondakov of Eastman Kokak Co.,
- ***Review of OLED Work in Japan*** by Junji Kido of Yamagata University,
- ***High-Performance Rear LCD Projection System*** by Seiichi Arakawa of Sony.

Special Events

The President's Reception and the Awards Banquet will be held on Monday evening, May 19. (Tickets for the Awards Banquet must be purchased in advance.) The formal opening of SID 2003, together with the keynote addresses, will be on Tuesday morning.

At the celebratory Wednesday luncheon, the annual SID/*Information Display* Display of the Year Awards will be presented to Kodak, Samsung Electronics, Optiva, Sony, and DuPont Holographics. SID's major personal-achievement awards will be presented at the Monday evening Awards Dinner. ■

Please send new product releases or news items to Information Display, c/o Palisades Convention Management, 411 Lafayette Street, 2nd Floor, New York, NY 10003.

Bending the Rules

When flexible displays are made, time-honored rules governing display fabrication and applications must literally be bent.

Peter J. Slikkerveer

IF five persons were asked to define a "flexible display," it would be apparent that it is a bit like defining "modern art" – it is difficult to define but they know one when they see one.

Flexible displays have great appeal – for many good reasons – but their applications are diverse. Just defining the field is not sufficient; we must also look beyond to examine which options are best suited for these applications and what obstacles may stand in the way of realizing their full potential. In the end, it may be that in order to bend a display, one must also have a flexible view of the display industry in general.

What Is a Flexible Display?

Designers have been enticed by the vision of flexible displays and electronic paper for at least ten years (Fig. 1). Flexible displays are considered to be more attractive than standard displays; they allow more freedom in design, promise smaller and more rugged devices, and could even replace paper. But there are many different types of flexible displays.

As a starting point, a flexible display will be defined as a flat-panel display made using thin, flexible substrates which can be bent to a radius of curvature of a few centimeters or less without loss of functionality. As a result, the displays made from these films can be curved over a single radius just as a sheet of paper.

Flexible displays can be further defined by how they are to be used for both existing and new applications. Four different categories have their own specific requirements for performance and mechanical characteristics: flat thin displays, curved displays, displays on flexible devices, and roll-up displays.

Flat Thin Displays

The displays in this first category will be in the flat configuration characteristic of current flat-panel displays (FPDs), but the thin substrates will make them thinner than current displays. They will also be lighter because less material is used and plastic replaces the heavier glass. The compliance of the display panel – originating in the thin substrates and their low Young's modulus – will add to the ruggedness of the display.

These attributes make the displays attractive for mobile applications such as laptops, PDAs, and cellular phones, by providing

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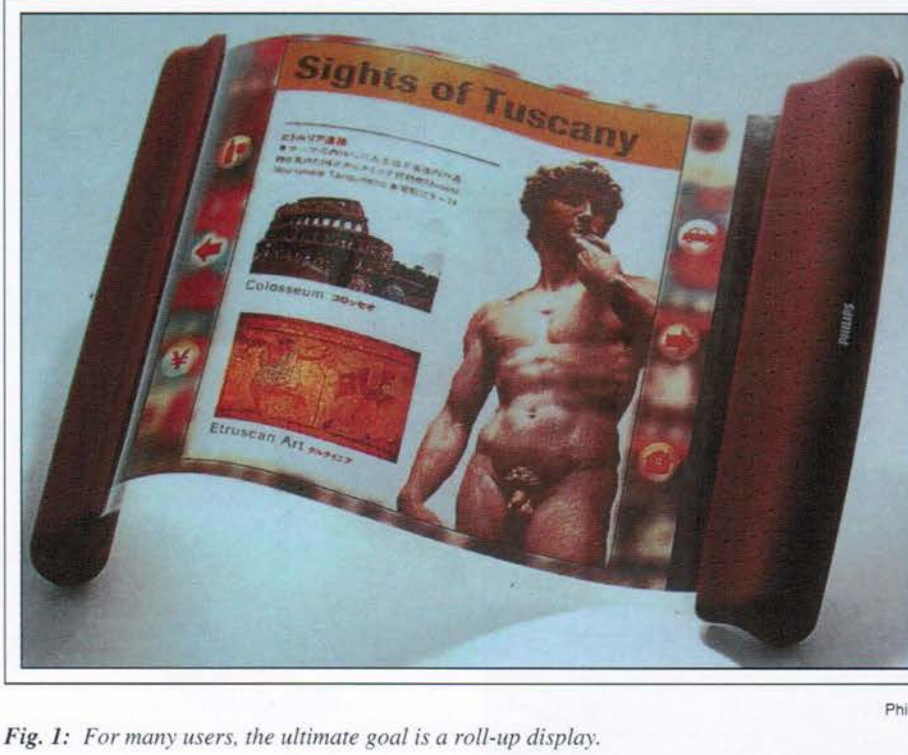

Philips

Fig. 1: *For many users, the ultimate goal is a roll-up display.*

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lighter, thinner, and more-rugged devices with larger displays. Plastic-processing technology also promises mass-produced non-rectangular displays, which will provide more freedom for designers and device makers, and will allow larger displays on handheld devices with organic shapes. Design studies of mobile devices have shown that the desire for non-rectangular displays has existed for many years.

Curved Displays

Displays in this category will be curved only once, when they are built into a module or a device. They will be used when curved, and will maintain that same curvature throughout their useful lifetime.

Curved displays will give product designers new freedom in designing products. They can adapt the curvature of the display to fit the curved surface of a product, such as a handheld device or an automobile dashboard. Curves are an advantage that can also assist in making devices smaller or improving their ease of use by providing new options for positioning displays; a display could actually wrap around the corners of the device.

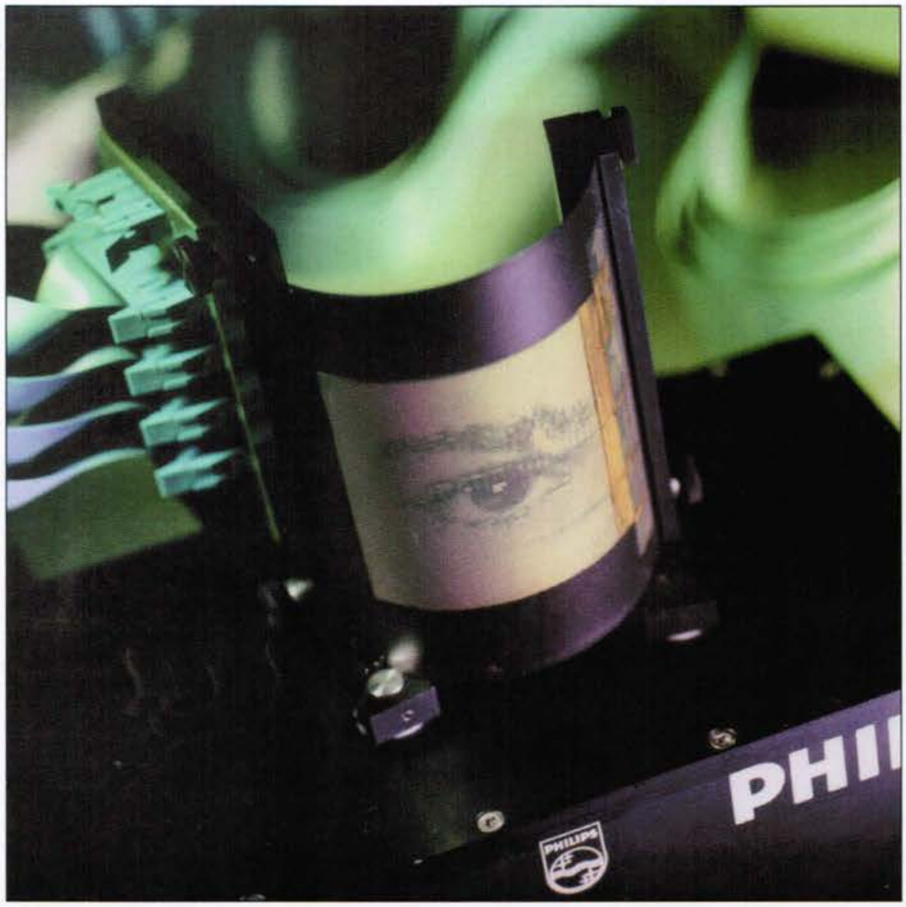
Displays on Flexible Devices

These displays must be at least as flexible as the devices in which they will be incorporated, such as displays in smart cards or clothing. They will have a default shape – flat for smart cards – but should allow frequent bending to some degree during use or storage. Miniaturization of handheld devices will make them thinner and automatically more flexible, requiring flexible displays in some stage.

Roll-Up Displays

Displays for mobile devices are subject to conflicting requirements; users want a display to be as large as possible when in use to allow easy access to complex data, but they would prefer to carry a small and lightweight device. A roll-up display could meet these conflicting requirements.

This application requires repeated rolling and unrolling of the display, preferably to a small diameter to allow a small package. This means that the display must either support large deformations or be very thin, or both. Since the display is used when unrolled, it probably would not be expected to function when rolled up.



Philips

Fig. 2: This cholesteric LCD has been bent to a radius of just 2 cm and still displays its image.

Candidate Display Technologies

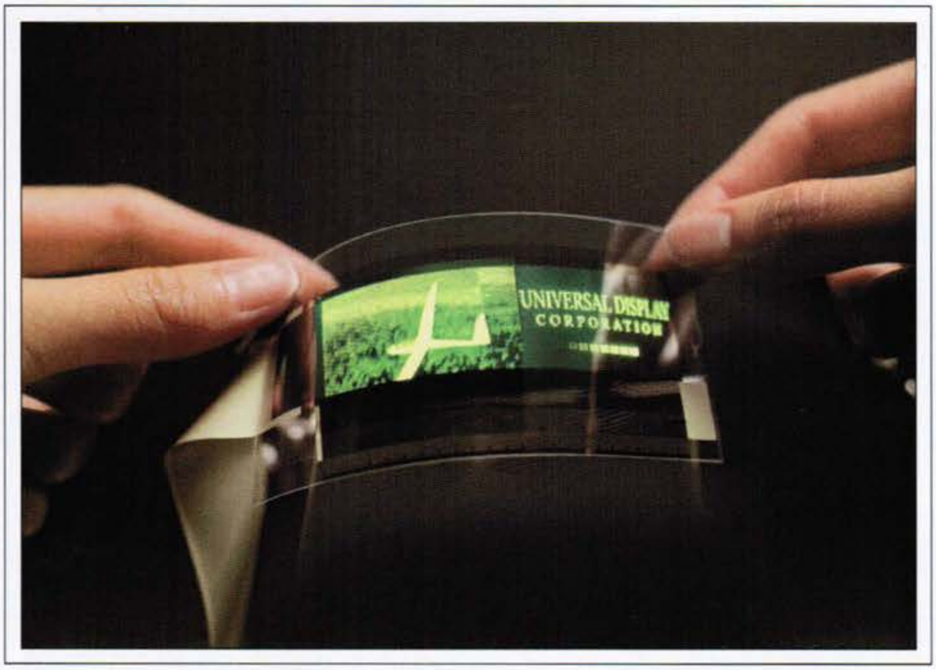
Thin substrates alone are not enough to create a suitable display; thin-display technology is also needed. Fortunately, a large number of FPD technologies have the potential to fulfill this requirement. The three most likely candidates today are liquid-crystal displays (LCDs), organic light-emitting-diode (OLED) displays, and electrophoretic displays.

LCDs are the dominant display in the flat-panel market, and have a long history of employing plastic substrates, beginning with the Texas Instruments work back in 1981. Plastic LCDs have suffered from a bad reputation for reliability and performance problems in the past, but recent advances show marked improvement. Full-color super-twisted-nematic (STN) and amorphous-silicon (a-Si) active-matrix panels have been demonstrated.

The LC layer is typically less than 10 μm thick, making them suitable for flexible displays (Fig. 2). One product – the Nike Triax watch – has already come to market with a curved LCD.

At this point, however, obtaining and maintaining control of the cell gap and the reliability of the display are the main problems with flexible LCDs. Recent developments give hope that these obstacles can be overcome.

OLED technology, both small-molecule and polymer, is widely viewed as one of the most promising developments in the display industry. The active layers are typically less than 1 μm thick, which should be ideal for flexible displays. Pioneer, Uniax, and Universal Display Corp. (UDC) are just a few of the many companies that have demonstrated OLEDs on flexible plastic substrates (Fig. 3). The challenge now is finding flexible ways



Universal Display Corp.

Fig. 3: Thin layers and emissive qualities of OLEDs make them well suited for flexible substrates.

for displays to cope with their extreme sensitivity to water and oxygen.

Electrophoretic displays, such as those produced by E-Ink Corp., rely on a relatively thick optical active layer of about tens of microns, where the liquid with electrostatic particles is encapsulated in polymers to form a coherent film. This solid film enables very flexible displays (Fig. 4). Although the display is rather slow – not fast enough for video – its front-of-screen performance and the option for flexibility give it a reasonable chance for replacing paper. The technology does not allow multiplexing, so flexible electronic-ink displays require a flexible active-matrix backplane.

Active-Matrix Approaches

All three of these leading candidate technologies require active-matrix backplanes to handle pixel switching for the larger or better-quality displays. Creating this matrix on a flexible substrate is not a trivial task, but several options exist.

As early as 1996, the first a-Si active-matrix display fabricated on plastic substrates using thin-film-diode technology was shown at EuroDisplay '96. This technology gradually developed into a 240 × 240-pixel color display that was shown at SID 2002 in Boston. This demonstrated that there are no fundamental roadblocks to making a-Si arrays on plastic, although a number of tough technological issues remain.

Polysilicon (poly-Si) offers greater electron mobility than a-Si. Several poly-Si transistors – but only a few displays – on plastic substrates have been demonstrated. Annealing the silicon layer poses significant challenges, such as lowering the processing temperature while maintaining throughput, high quality, and high yield. Claimed process temperatures now vary from 275°C to as low as 100°C.

A new approach is to use organic semiconductors to create the active matrix. Instead of relying on vacuum deposition and lithography, these devices can be created with wet processing or possibly even ink-jet-printing technology. Issues remain in proving lifetime and reliability of the new materials used in plastic electronics.

The Challenges?

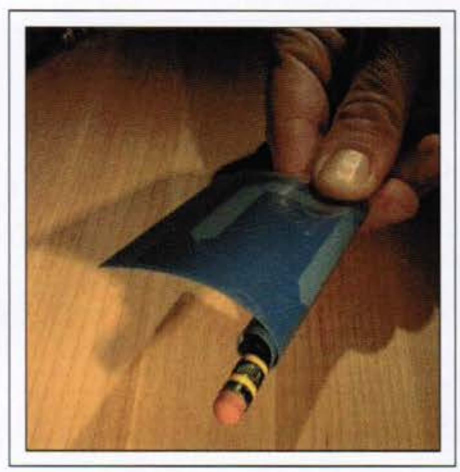
While there are plenty of choices of technology to use for flexible displays, a long list of obstacles remain to be overcome before mass production can be feasible. Some of these are particular to individual display technologies, while most are more or less shared by all the players. These problems can be broken into three large groups: substrates, processing, and mechanics.

Substrates

For many applications, display substrates need to be not just transparent, but of optical quality. They must be dimensionally stable to allow patterning over large distances and to offer chemical resistance to the corrosive chemicals typically used in display processing. Although the process temperature is being brought down, the substrates should be able to withstand temperatures between 150 and 300°C.

At this moment, there are several options available, and many more are being developed. Most substrates, however, are combinations of organic and inorganic layers. Thin glass films from 30 to 150 μm are coated with organic resins to reduce their fragility. Bare polymer films, for example, do not possess the required chemical inertness or barrier properties. The barriers are necessary because many display technologies cannot operate in ambient conditions, so the display layer must be shielded reliably. To obtain a suitable display substrate, the polymer films are often coated with a number of organic and inorganic layers.

There is significant worldwide effort devoted to developing plastic substrates. For the last decade, Japanese companies – such as Sumitomo Bakelite and Teijin – have worked energetically to develop suitable display sub-



E-Ink Corp.

***Fig. 4:** Electrophoretic displays are relatively thick but very flexible. This early prototype can be rolled to an impressively small radius.*

strates, and they are now in production. Partly coordinated by the U.S. Display Consortium, there is significant activity in the manufacture of display substrates in the United States – including efforts by Promerus and Vitex – while some activity has also been initiated in Europe by Ferrania. The plastic substrates are being fully engineered with all coatings, and the maximum process temperature of the substrates is being increased from 150°C to as high as 400°C.

A special issue is the development of hermetically sealed gas and water-vapor barriers for OLEDs. Much progress has been reported, but it is difficult to evaluate the current status simply because there is no standard for measuring water-vapor permeabilities below 10^{-3} gram/m^2/day. A calcium-degradation test is being used to classify the barrier layers, but there is no standard method of testing.

The cost of plastic substrates is another obstacle to mass production. Engineered plastics currently sell from $200 to $300 per square meter, compared to glass substrates at one-half to one-sixth the cost. Based on the cost alone, two future scenarios are possible. Either the flexible-display price will become cheaper than that of the glass displays, in which case it can be expected that the entire display industry will change to the new flexible substrates, or the price will remain comparable to glass or above, which will limit flexible substrates to a niche market in the display world. The high price of plastic substrates makes the first scenario very challenging.

Processing

A suitable substrate is not in itself sufficient for the mass production of flexible displays. The mechanical difference between the rigid glass and the flexible plastic display substrates might require very different methods of processing in the factory.

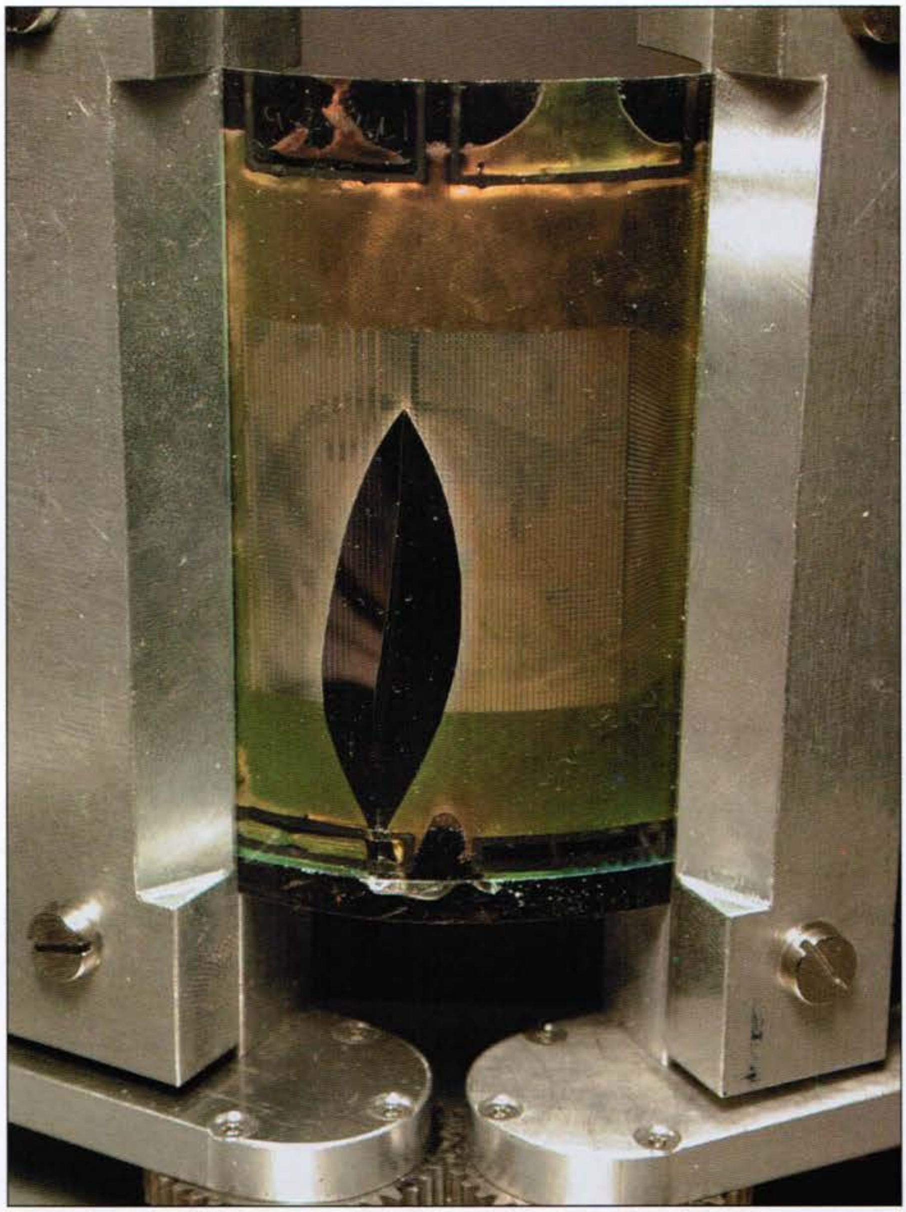
The most important problem is how the thin flexible films will be handled. Conventional production methods will not suffice and must be adapted. Since all process steps are involved, it could require a new type of display factory.

Another important issue for plastic-based substrates is the registration of multi-mask patterns. The film can become dimensionally distorted by thermal effects or by solvent swelling. Pre-annealing the substrate might greatly reduce irreversible effects, and careful process design can reduce reversible effects such as solvent swelling. However, it is very likely that alignment equipment will require special adaptations.

Organic layers in the display substrate will often require low-temperature processes, which means that a significant part of the process will have to be modified, along with the materials used for everything from deposition steps to types of photoresist.

Mechanics

The new types of substrates – and applications that require bending the displays – give rise to a completely new set of mechanical issues. Most existing displays are mounted in ways designed to avoid mechanical stress, which is impossible for flexible or curved displays. Instead, the entire display must be optimized for mechanical deformation. In LCDs, this involves main-



Philips

Fig. 5: *Flexible substrates are not immune to mechanical forces, and stresses can cause display-destroying fractures.*

taining a consistent cell gap during mechanical deformation. And all flexible displays must be designed to handle the mechanical stress at their edges during deformation.

Substrates that combine a number of organic and inorganic layers pose special mechanical and chemical challenges. Good adhesion between all layers must be maintained, and fracture of brittle inorganic layers must be prevented. Residual stresses after deposition of the coating layers during substrate manufacture or during display processing can cause undesirable curving of the substrate. Another important cause of mechanical stress and curving is the difference in thermal expansion between the inorganic materials (typically less than 10 ppm/°C) and the organic materials (usually more than 50 ppm/°C). The stresses that occur during high-temperature processing might lead to the failure of some of the functional layers.

Even though plastic films appear to be durable and resilient, the high-temperature plastics in display substrates are normally used at temperatures far below their glass-transition temperatures. This makes them brittle and prone to cracking when stressed. Substrate failure or fracture is therefore a significant cause of failure in flexible displays (Fig. 5).

These stress problems are accentuated because the new flexible displays are intended to be more rugged than traditional designs. Even though a flexible display is compliant with some device deformations, it is not indestructible. For example, local contact with hard, sharp objects can easily destroy a display. The numerous mechanical challenges must be resolved before flexible displays can live up to the expectations of product designers and end users.

The Future Is Flexible

Although flexible displays appear to be merely flexible versions of FPDs, a closer look reveals that they might be different in significant ways. These differences will determine how they are incorporated into products that serve both existing applications and new markets, as well as how they are designed and manufactured. They will require more than just bending the rules by which the current displays are made; they may require an altogether new set of rules.

There are certainly a number of appealing display technologies that hold great promise, but progress may come slowly. We may well be a number of years away from a practical roll-up display that has a chance of commercial success.

To get to that point, we must expect to make sweeping changes. Changing over from glass substrates to new organic–inorganic substrates has major implications for the entire display industry, perhaps requiring completely new factories as well as a new technology platform to serve them. It may well take a new application to drive demand for flexible displays in order to produce the revenues required to cover development costs and overcome the roadblock of building a new manufacturing infrastructure.

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Back to the Future

A look at the history of display development can help us make R&D funding decisions that will take us profitably into the future.

by Allan R. Kmetz

THE HISTORY of flat-panel-display (FPD) development presents an overall pattern of relatively steady evolution resulting from the interplay of scientific breakthroughs, market forces, and corporate policies. But FPD history also reveals cases in which failed ideas sprout again in response to new technical conditions or a new generation of venture capitalists. What implications can we draw from this history for the future of displays, including organic light-emitting-diode (OLED) displays, microdisplays, and electronic paper?

But let's start close to the dawn of FPD history. Thirty years ago, the cathode-ray tube (CRT) for television was the only display of commercial significance. Integrated circuits (ICs) were still relatively new, and their application in mass markets was just beginning. CRTs teamed with semiconductor memory appeared in interactive terminals for airline ticketing, several four-function electronic calculators came on the market, and the first digital wristwatches were shown, but the IBM PC was still a decade away.

Despite the lack of an established target market, there was so much research on so many different kinds of displays that in 1973 the *Proceedings of the IEEE* organized a special issue entitled "New Materials for Display Devices." There were papers on CRTs, LEDs, plasma panels, electroluminescent displays, solid ferroelectrics, liquid crystals, and electrophoretics – and that did not exhaust the display effects that were mentioned.

It was this striking diversity that concerned the authors of the lead-off overview paper in that Proceedings.[1] Gordon and Anderson, two Bell Labs research managers, wrote "The pur-

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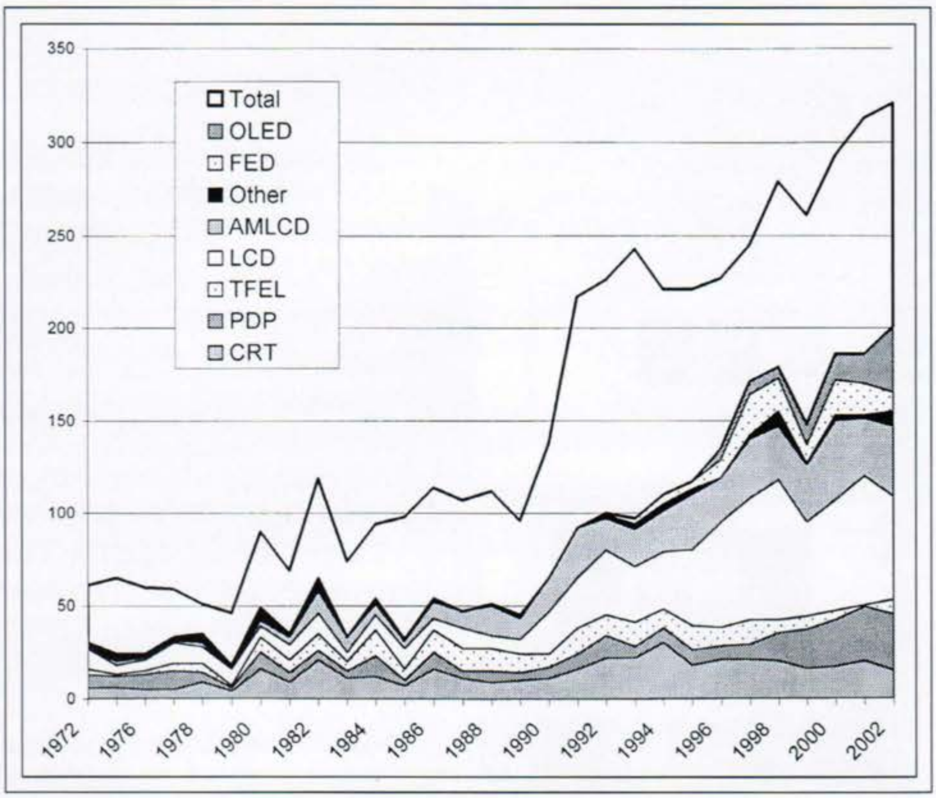

Fig. 1: *Shown is the number of papers presented each year at the SID Symposium on the various principal display device technologies. The remaining (unlabeled) papers that made up the totals at the conferences dealt with systems, applications, and human factors rather than devices.*

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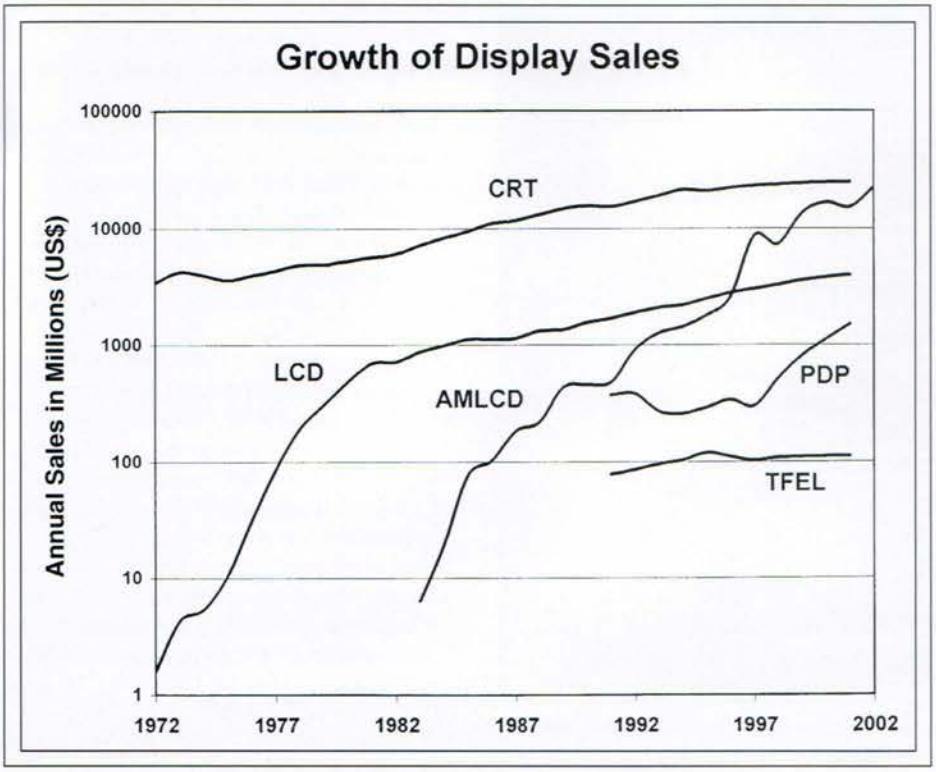


Fig. 2: Annual sales of various displays. (Source: iSuppli/Stanford Resources.)

suit of new display technology has been characterized by many starters but very, very few finishers ... we are concerned that too little justification is being required of display scientists and engineers.... In the long run, this could only be harmful to the display community, to the general utility of displays, and to the financial health of the electronics industry."

Gordon and Anderson recognized that it would be very difficult for any new technology to displace the CRT from its established markets, and they feared that following too many approaches would squander the limited resources of display science on subcritical efforts doomed to failure. Their paper provoked a storm of outrage and anger from display researchers who felt their work denigrated and their funding endangered. Now, 30 years later, we can ask whether they were right.

Few Finishers?

We can examine the history of display development by following the Table of Contents of the annual *SID International Symposium Digest of Technical Papers* that has been published for the last 33 years (Fig. 1). In 1972, there were certainly papers on CRTs, but plasma (PDP) and electroluminescent (TFEL) displays were also well represented, and researchers were feeling out a variety of liquid-crystal-display (LCD) effects and even multiplexing schemes. Just a year later, SID had its first active-matrix (AMLCD) papers. The remaining papers that made up the totals at the conferences dealt with systems, applications, and human factors rather than devices.

A striking aspect of the chart is the growth in the size of the conference, especially around 1990 when SID added more parallel sessions and then posters in response to growth in the number of papers submitted. Clearly, display R&D is not the limited resource that Gordon and Anderson implied. Looking more closely at the figure, we see that while 30 years elapse none of the principal display R&D categories dies out. In fact, new categories have been added in the last decade for field-emission displays (FEDs) and OLED displays.

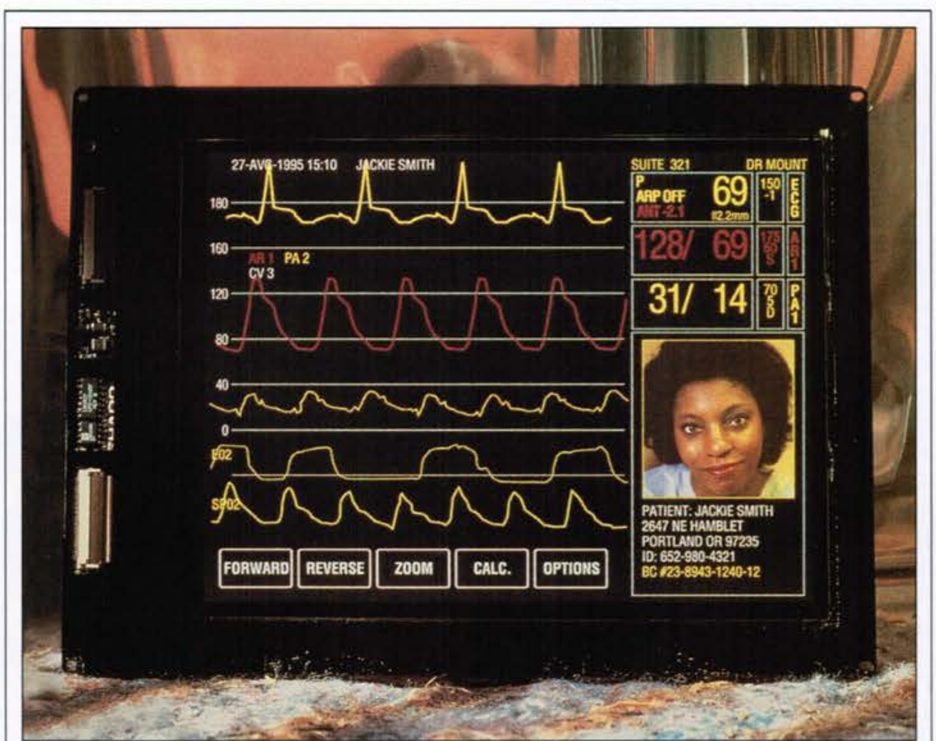
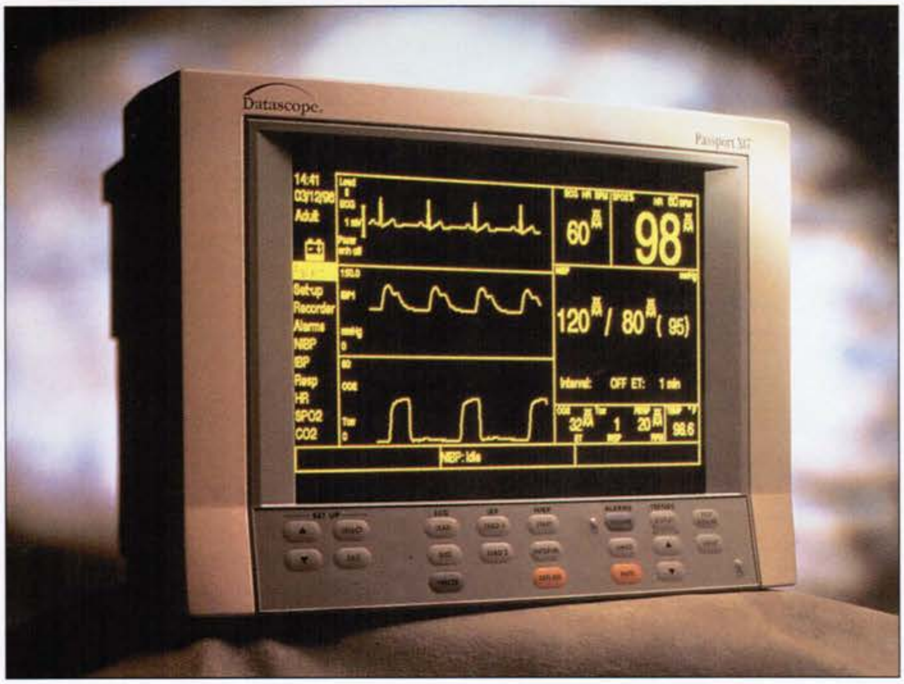


Fig. 3: 1995: Sharp's 6.4-in. color VGA AMLCD. This panel was aimed at industrial systems, but larger AMLCD panels were being made by several manufacturers for PCs at this time.

Sharp Corp.



Planar Systems, Inc.

***Fig. 4:** 1996: A Planar VGA ICEBrite™ TFEL display in a Datascope Passport® XG Patient Monitor. Planar boasted that its display gave Datascope the brightest display in the patient-monitoring industry.*

Gordon and Anderson defined as a failure a display technology that never becomes a finished, successful product. But a look at the annual sales for the various display types indicates that none of them is a failure by this standard (Fig. 2). As expected, the CRT is by far the largest, but the rise of LCDs through the early 1980s is dramatic, to about a tenth of CRT sales. Plasma and electroluminescent displays had relatively steady sales of about an order of magnitude lower. As soon as the LCD growth slows, the AMLCD starts its bumpy climb to dominance.

Comparing Figs. 1 and 2, there is evidently a strong correlation between the level of R&D activity in a technology and sales revenue. Either a successful product can afford to support more development or investment in development leads to new products. Display scientists and engineers should be gratified by either conclusion, but I think both are true.

Patterns of Growth: LCDs/AMLCDs

The remarkable evolution of LCD technology was fueled by a progression of new products that created markets where none had existed before. In the early 1970s, visual performance, manufacturability, and reliability came together in the twisted-nematic (TN) LCD in a hermetic glass package.[2] A few segmented numerics could be directly addressed by a CMOS IC with power consumption orders of magnitude lower than that of any other display. A new consumer mass market for digital wristwatches was born.

By the late 1970s, the development of stable liquid crystals such as cyanobiphenyls obviated the hermetic package.[3] Epoxy sealing and rubbed polyimide alignment made low-level multiplexing possible and facilitated batch fabrication of multiple LCDs on a 10-cm glass "wafer." The low-cost LCD calculator powered by solar cells swept the world.

The PC Era

In 1981, the IBM PC was introduced, and LCD manufacturers soon realized that a portable version was another market opportunity, but multiplexing a TN liquid crystal to such a high level was impossible. The only alternative appeared to be active-matrix addressing, and the major manufacturers committed major resources to overcome the formidable problems of developing an entirely new IC process on large glass substrates. Viable products with acceptable yields were years away.

Suddenly, in 1985, the supertwisted-nematic (STN) display was invented in Switzerland at Brown Boveri.[4] But the company, daunted by the investment required to capitalize on this breakthrough, withdrew from LCD manufacture. Partner Philips deferred investment. Japan, despite substantial commitments to AMLCD development, recognized the value of a near-term solution. When performance was compromised to gain early manufacturability, monochrome portable PCs became a commercial success, and then the Gameboy was born. Color was soon achieved through compensation techniques, and slow response was mitigated by software tricks such as cursors with "comet tails."

By the early 1990s, the heavy investment in amorphous-silicon (a-Si) TFT AMLCDs paid off: superior performance captured the growing market for laptop displays (Fig. 3). In the late 1990s, painful susceptibility to the cyclical variations in the laptop business motivated efforts to develop other markets. Television was the most obvious opportunity, but LCDs were notorious for poor field of view. Then Hitachi demonstrated in-plane switching (IPS),[5] the first of several new LC effects that finally solved the viewing-angle limitations. In the new millennium, AMLCD desktop monitors and television products are gaining market share from the CRT, while passive LCDs serve handheld applications such as cellular phones and PDAs. The combined sales of all LCDs now exceed CRT sales.

Early Flat Emissive Displays

Plasma-display panels (PDPs) and thin-film electroluminescent (TFEL) displays had a head start on LCDs: they enjoyed good visual appearance and sharp threshold voltages that permitted multiplexed addressing. But, lacking a unique advantage such as the extreme low power that opened new markets for the LCD, they competed with each other and with the CRT. In the 1980s, they established their market niches: relatively large banking and military displays for plasma technology and relatively small, rugged military and medical displays for TFEL (Fig. 4). LCDs won the race to provide full color, and their low-voltage requirement gave them a substantial advantage in the cost of driver circuits.

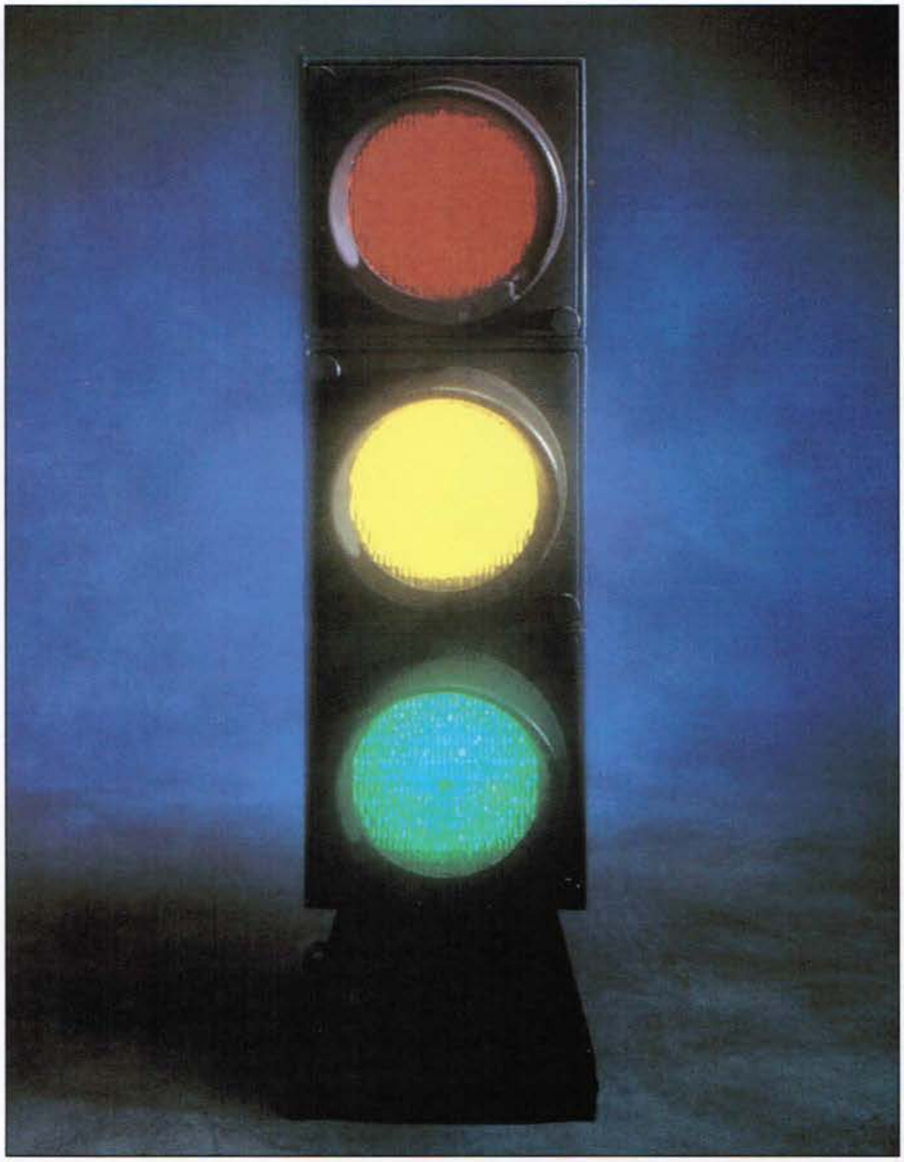
Color came to both PDPs and TFEL displays in the 1990s. The PDP emerged with a completely new structure, the three-electrode surface-discharge cell with barrier-rib isolation,[6] and a new addressing method for digital gray scale, the Address-Display-Separation method.[7] At last a unique advantage for plasma was recognized: it became the only FPD technology with the potential to meet the needs of 40–60-in. HDTVs. PDP sales increased after 1997, mostly for advertising and public-information displays. Figure 1 shows a corresponding increase in R&D activity in PDPs, reflecting efforts to increase luminous efficiency, solve motion artifacts, and, above all, to reduce costs. With many companies involved, further improvements are sure to come, but competition – especially from projection displays – will be intense.

Blue Emission

Gordon and Anderson singled out the blue LED for particular scorn. Red and green LEDs were well established for indicators and small numerics, but they said the trend in efficiency as a function of wavelength made a practical blue unlikely. "Given the cost of developing an entirely new materials technology, the poor prospects for competing with a highly developed technology well down the learning curve, and the dubious advantage of providing one more color when there are already several, the quest for blue LEDs surely does not represent a reasonable investment of research and development effort."

Indeed, papers on new display applications of LEDs virtually disappeared from the SID Symposium, and little progress toward a blue LED was evident for almost 20 years. Still, the LED industry enjoyed a robust market for indicators, and work to improve emission efficiency was ongoing. By the late 1980s, red LEDs were more efficient than filtered incandescent lamps for automobile taillights.

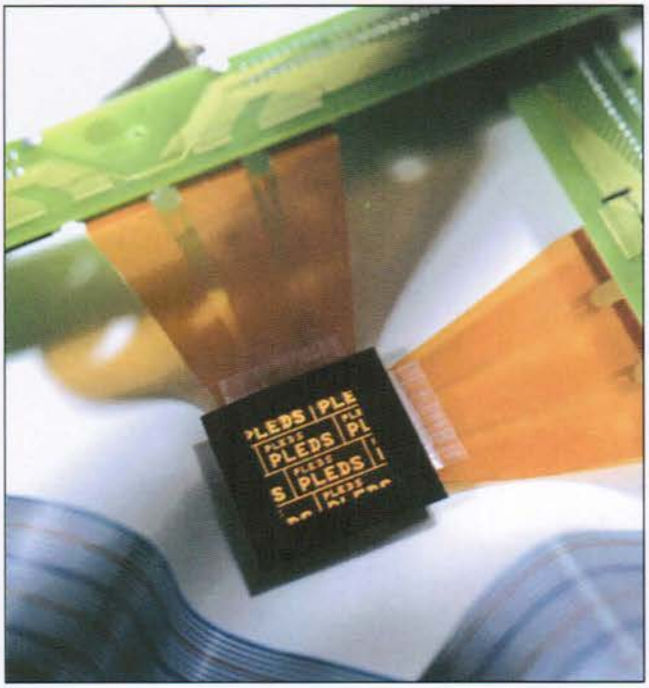
Unexpectedly, in 1995, Nakamura at Nichia Chemical reported efficient blue and green emission from a new material system, InGaN.[8] This was truly a breakthrough, and LEDs were soon available in red, green, and blue, with efficiencies better than unfiltered incandescents (Fig. 5). Spectacular full-color video billboards, solid-state traffic lights, pocket flashlights using blue LEDs with yellow phosphor for intense "white" light, and long-life rugged tricolor LED replacements for white incandescent lamps (with the added benefit of tunable hue) are new markets created by the successful search for a blue LED.



Hewlett-Packard Co.

Fig. 5: 1998: Hewlett-Packard demonstrated this all-LED traffic signal upon the introduction of its high-efficiency green LEDs and green-LED traffic-signal lamps.

Shortly before the announcement of GaN, light emission, including blue, was reported with decent efficiency from organic materials, first small-molecule heterostructure LEDs from Kodak[9] and then conjugated polymer LEDs from Cambridge Display Technology.[10] With low-voltage dc drive and potentially simple area fabrication, successful development of OLEDs clearly could have a revolutionary impact. In less than a decade, more than 85 companies have become involved in OLEDs and progress has been rapid (Fig. 6). Efficiency and lifetime are improving, the first commercial products are on the market, and gee-whiz prototypes of full-color video AMOLEDs exist.



Philips Research

Fig. 6: Circa 1999: Philips Research demonstrated this PolyLED™ polymer-OLED prototype with 87 rows and 80 columns.

Matsushita Electric Industrial Co.

Fig. 7: 1994: Matsushita's Flat Vision TV – which was available very briefly in Japan – contained the company's flat "beam-matrix" tube, one of several attempts to make a commercially successful flat CRT.

Adaptation of technologies developed for other displays, such as TFT arrays for AMLCDs, is contributing to continuous rapid progress, but there are still many problems of manufacturability, reliability, cost, and performance to be solved.

Electronic Paper and FEDs

Not all display concepts are able to find and serve a market that will sustain further development. Remarkably, those failed concepts often return for reconsideration, sometimes many times. The electrophoretic display introduced in 1972 had a very pleasing appearance, but failed because of reliability problems and lack of a threshold for multiplexing.[11] Philips brought it back in 1977 with a new triode structure that provided a threshold, but its appearance was worse and reliability problems persisted.

In 1986, an Exxon venture made a 2000-character triode prototype but no product. In 1998, NOK[12] and E-Ink Corp.[13] separately reported on the combination of an electrophoretic display with two techniques from the LCD world: microencapsulation to keep the distribution of particles uniform and a TFT array for active-matrix addressing. Now, with impressive technical results, it remains for the marketplace to determine whether "electronic paper" will be a success.

Another recurrent theme is the flat CRT. There had been earlier attempts at a flat CRT with colorful names like the Apple tube and the Banana tube, using various unsuccessful ways of folding the deflected e-beam, but in 1972 the Best Paper Award at the SID Symposium went to the Northrop Digisplay. In this device, multiple hot wires were used as an area emitter of electrons, and a stack of digitally addressed grids controlled electron access to the phosphor. Fabrication problems and high addressing power prevented it from becoming a product.

Six years later, Texas Instruments revived the idea, again won best paper, and then failed for the same reasons. Seven years later, Matsushita reported a flat CRT that combined matrix selection with local deflection (Fig. 7). After a token appearance as a 14-in. color product in 1994, it too vanished.

Since about 1990, field-emission displays (FEDs) have caused great excitement as the new flat CRT, with many expecting FEDs to take over the TV market after a brief period of relatively inexpensive development. FEDs use an area cold cathode, initially some form of Spindt microtips, and, lately, carbon nanotubes or some sort of planar emitter, usually with a single-layer grid and proximity focus onto the phosphor screen. Problems with manufacturability and reliability have caused the number of proponents to dwindle and the target applications to shift to smaller displays with special requirements, such as transportation displays, where FEDs must compete directly with LCDs, TFELs, and OLEDs.

Going It Alone

It is widely believed that a successful technology needs a critical mass of at least three serious participants, but there are instances in which a single champion has gone the distance alone. Research Frontiers provided a living for its handful of employees for 30 years while developing intellectual property based on a 1934 invention by E. H. Land for a colloidal dipole suspension display. Despite sporadic publication through SID and occasional exploratory licenses, no long-term partner joined them. Recently, the little company found success by microencapsulating its suspension for stability and ease of fabrication. Now a publicly traded company, its technology is widely licensed, not for displays but for electrically dimmed windows.

A more familiar example of the success of a display technology with a single champion is the Texas Instruments Digital Micromirror Device (DMD™). Research on a microelectromechanical-system (MEMS) light modulator began at TI in the 1970s. The basic DMD was invented in 1987, and it underwent major alterations to fix problems and improve performance until the first products were sold in 1996. Since then continuous development efforts at TI substantially improved contrast ratio and other performance parameters. The DMD is now used in products ranging from ultraportable projectors to digital cinema.[14]

Back to the Future

Obviously, the fear expressed by Gordon and Anderson that the display industry would suffer from too many different technologies was unfounded. The industry has enjoyed robust growth, largely through the development of new markets that would not have been possible without enabling advances in display technology.

There are clearly many different definitions of success. Major investment by many providers can achieve cost and performance improvements that turn a small market into a mass market, but even a small niche market can sustain an appropriately small number of providers of displays with specialized properties.

Gordon and Anderson were afraid that researchers were embarking on projects without due consideration of the risks, but they were not very clear about how the risks could be predicted and evaluated. No manager, at least no American manager, would begin a project if he knew it wouldn't pay off for 30 years. On the other hand, a small project with a low probability of eventual success might be affordable – like buying a lottery ticket. With sufficient progress, the level of investment might be increased in the expectation that success is imminent. But it would be wise to examine the project in light of display history to assure that the critical problems found in the past are faced in the beginning.

If problems persist and spending continues, the managers must re-examine the risk to decide whether to continue the project. The money already spent is unrecoverable. The question is whether a new expenditure is likely to achieve the project goals. One can imagine that, with good progress demonstrated every year and uncertainty about how far away the goal is, affirmative decisions could repeat for decades. The history of displays over the past 30 years is rich with examples of such patience being rewarded by inventive breakthroughs.

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conference report

That's Entertainment!

The coverage was broad, but a major thread at the Flat Information Display Conference highlighted the growing importance of non-IT markets for FPDs.

by Alfred Poor

MONTEREY, California, is the land of John Steinbeck, fantastic marine life, and world-class golf courses. And for the 19th consecutive year, it was also the home of the iSuppli/Stanford Resources Flat Information Display Conference, held December 9–11, 2002. About 300 key representatives from display-industry companies from around the world converged on this beautiful city on Monterey Bay for an informal yet intensive exploration of the current and future state of flat-panel displays (FPDs).

The two-day technical conference featured a packed schedule of presentations by industry experts, organized into thematic sections. The conference kicked off with a keynote address by Dr. Balaji Krishnamurthy, President and CEO of Planar Systems since 1999, where he has guided his company's radical conversion from the development and manufacture of electroluminescent panels to a company that designs and markets complete displays for business and entertainment applications. He made the point that the most profitable companies are near the consumer end of the supply chain, where they can be more agile and respond more quickly to changing market demands.

Planar has shifted its business from component production to services and solutions, focusing more on market applications than on general technology principles. The company assets have shifted from physical plants to the intellectual know-how of its employees, moving from proprietary and vertical products to open and leveraged designs. As a result, the company's gross margins have increased from about 25% to about 33%.

Following the keynote, Paul Semenza, Executive Vice President of iSuppli/Stanford Resources, provided an overview of the display market. The company's forecasts indicate that the worldwide electronic display market – in terms of value of total sales – will nearly double from 2001 to 2006 and that nearly all this growth will be supplied by LCDs of various sorts. He also pointed out that CRT sales values are projected to remain more or less constant over the period, neither growing nor declining.

Semenza also took time to present a plaque to Joseph Castellano in recognition of his contributions to the display industry, both as a researcher at RCA's David Sarnoff Research Center who helped develop the first LCD in

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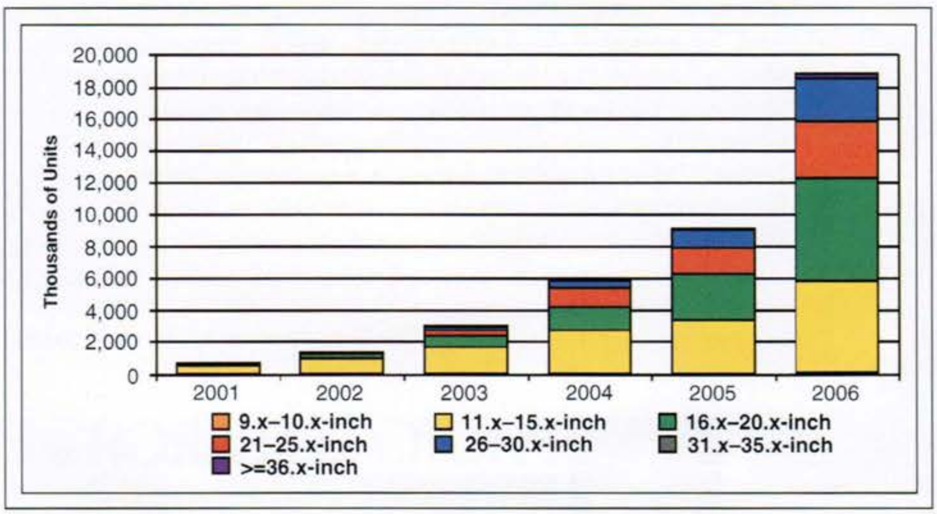

***Fig. 1:** LCD production is growing fast, and the largest unit growth of all will be in large LCD TVs. This year's 1.4 million units are projected to increase to more than 18 million units by 2006. (Data and graphic courtesy of iSuppli/Stanford Resources.)*

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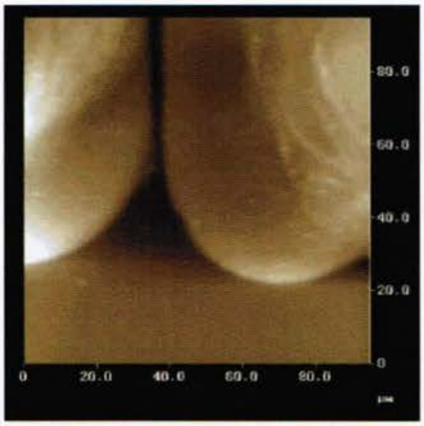


Plastic Logic

Fig. 2: New techniques in ink-jet-printed plastic semiconductors using hydrophobic and hydrophilic materials to control critical dimensions have reduced gaps from 200 μm to as small as 0.25 μm.

1965 and as Founder of Stanford Resources to track and project display-industry activity. He retired at the end of 2002 and has plans to write a book that chronicles early research in liquid-crystal technology.

An executive roundtable discussion – moderated by this author – tackled the topic of "Technology Push versus Market Pull: If You Build It, Will They Come?" Representatives from LG.Philips LCD, Microsoft Corp., NEC–Mitsubishi, Toppoly, RiTdisplay Corp., and IDTech fielded wide-ranging questions from the audience, shedding some light on the difficulties involved in moving technology from the lab to the buyer's desk or living room.

The remainder of the first day was filled with three topical sessions, followed by another five on the second day. The same structure guided each session. An iSuppli/Stanford Resources analyst started with an overview of the current market, projections for the next 5 years, and an analysis of the various forces at work within that market segment. Then three or four experts from companies within that segment gave 15-minute presentations highlighting one aspect or another of the topic. Each session concluded with a question-and-answer period, which gave participants an opportunity to probe further into specific points of interest. As might be imagined, this format created a dense and steady flow of information worthy of the "drinking from a fire hose" metaphor, with far more content than could be summarized here even if we managed to convince the editor to devote the entire issue to this report. So the following highlights are intended to provide a taste of the overall proceedings, rather than a comprehensive account.

LCDs: The 800-pound Gorilla

The LCD session was dominated by talk of fifth- and sixth-generation fabs, crystal cycles, and the move to large displays for television applications. According to Sweta Dash of iSuppli/Stanford Resources, the desktop-LCD-monitor market will continue to grow, but portable displays 9 in. and larger will grow even faster. Also, 15-in. panels are poised to displace 14-in. screens in the portable market. The largest growth of all, however, will be in large LCD TVs: 1.4 million units this year will increase to more than 18 million units by 2006 (Fig. 1).

Takahisa Hashimoto, President of IDTech, made the case that higher-resolution displays increase productivity over displays with fewer pixels. A display with 2 million pixels or more eliminates the need for scrolling, and results in a two- to tenfold productivity gain over VGA displays. He also mentioned a pixel-level multiplexing design that is already shipping, which cuts the number of required driver chips in half.

Carl Steudle, V.P. of Marketing for LG.Philips LCD, provided an inspiring view of the many ways that LCDs can be incorporated into a variety of devices to enhance life both at work and at home. Dedicated and multi-use, within and beyond the reach of the viewer, stationary and portable, the future is rich with possibilities, Steudle said.

Kimberly Allen of iSuppli/Stanford Resources kicked off the Emerging Technologies session by focusing on the appeal of plastic substrates and the advantages of

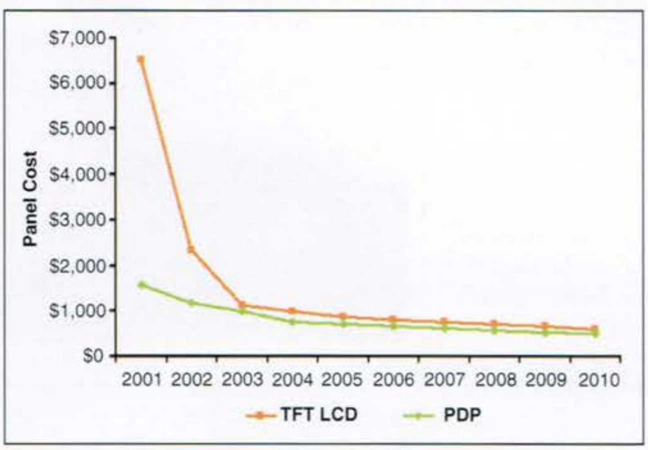
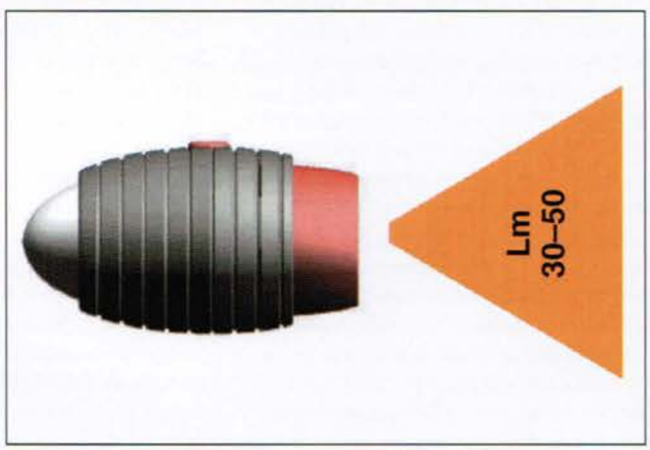


Fig. 3: David Mentley of iSuppli/Stanford Resources showed that production costs for a 40-in. wide-VGA LCD panel will practically match PDP costs as early as 2003, at slightly more than $1000. (Courtesy of iSuppli/Stanford Resources.)



Lumileds Lighting

Fig. 4: Menko de Roos of Lumileds Lighting said that high-brightness LEDs can be used to make "pocket projectors" capable of creating letter-sized images that could be used with products ranging from PDAs and notebook computers to digital cameras.

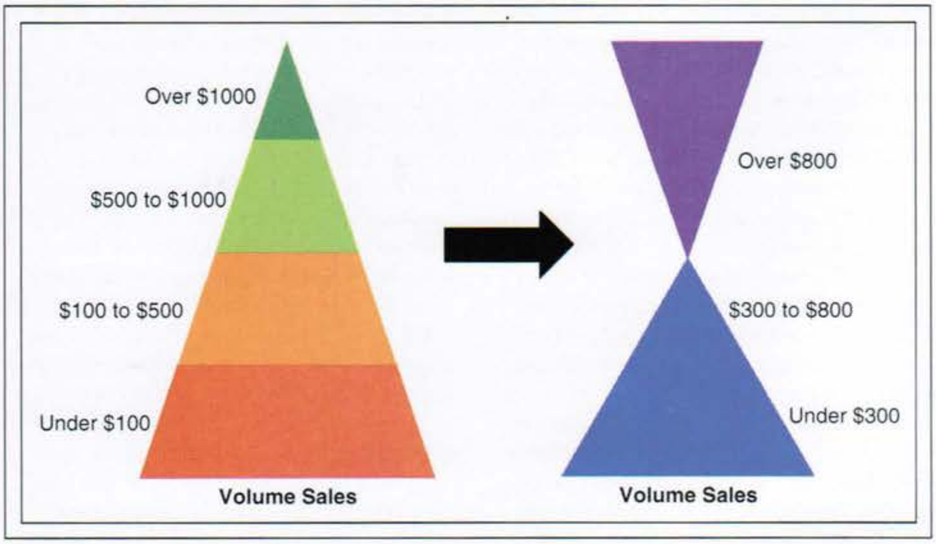


Fig. 5: The current market for entertainment-oriented consumer electronics is not shaped like the traditional pyramid, with highest-priced items selling the fewest units. It is more like an hourglass, in that mid-range items sell the least, with the least- and most-expensive items selling in higher quantities. (Courtesy of iSuppli/Stanford Resources.)

roll-to-roll processing. She also encouraged rational pursuit of these innovations, although not all applications will benefit from them. George Mihalakis, CEO of Gain Micro-Optics, Inc., provided some interesting insights into why rear-projection televisions may be the winning approach to digital entertainment displays in living rooms due to their ample size and wide viewing angles that suit multiple viewers.

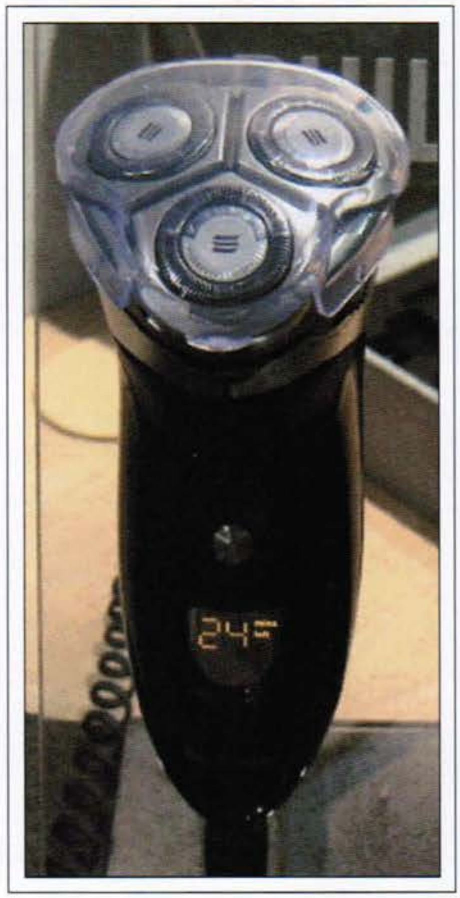
Stuart Evans, CEO of Plastic Logic, gave an overview of recent advances in plastic semiconductors using hydrophobic and hydrophilic materials to control critical dimensions. Where early ink-jet experiments produced gaps of about 200 μm, new techniques relying on surface-tension forces have created gaps as small as 0.25 μm (Fig. 2). When ink-jet printing technology is further refined beyond the resolutions required for printing text and photos on paper there will be opportunities to utilize it in displays and plastic semiconductors, which can benefit from much finer structures.

The "Display Life Cycle" focused largely on how production costs decline over the life span of the product. David Mentley of iSuppli/Stanford Resources shared projections, indicating that 20-in. LCD panels could cost as little as $200 5 years from now, with "no heroic interventions" required. A technology breakthrough could lower the price even further. He also showed that production costs for a 40-in. wide-VGA LCD panel will practically match plasma-display-panel (PDP) costs as early as 2003, at slightly more than $1000 (Fig. 3).

Reiner Mauch, President of Schott Glass, pointed out that his company now produces 30 tons of glass substrates for TFT-LCDs each day compared with the 300 tons they produce daily for CRT production. Donald Yeaman of M+W Zander described his company's efforts to help LCD manufacturers reduce production costs through more efficient use of energy and materials. In one set of examples, he showed how an analysis of water management in six fabs yielded savings of 20–50%. And Menko de Roos of Lumileds Lighting demonstrated the company's high-brightness LEDs, and discussed how they can be used to advantage in LCD-panel backlights, rear-projection televisions, and "pocket projectors" capable of creating letter-sized images that could be used in or with everything from PDAs and notebook computers to digital cameras (Fig. 4).

Singing and Dancing

The shift of attention away from IT applications and toward entertainment and consumer electronics came into sharp focus during the "Enabling Advanced Television" session. iSuppli/Stanford Resources analyst Jay Srivatsa illustrated that this can be a tricky area in which to make a profit on hardware sales. He noted that Wal-Mart has sold an Apex DVD player for $38 that cost at least $30 to manufacture and that Microsoft's Xbox sells for $199, but the components cost at least $300. He also made the point that the current market is not shaped like the traditional pyramid, with the highest-priced items selling the fewest units. Instead, it is more like an hourglass, in that mid-range items sell the least, with the least- and most-expensive items selling in higher quantities (Fig. 5). Parviz Khodi, V.P. of Marketing at Silicon Image, discussed the recently approved High



Philips and Covion

Fig. 6: The first consumer product incorporating an OLED display has hit the market: Philips/Norelco's rechargeable electric shaver incorporating a monochrome OLED battery meter by Philips Integrated Device Technologies using Covion's OLED material. For an interesting viewpoint, see the "Letters to the Editor" column in this issue.

Definition Multimedia Interface (HDMI) standard that uses a single bi-directional connection to carry digital video and audio signals – up to eight channels at once – supporting up to 1080p video.

Rhoda Alexander of iSuppli/Stanford Resources introduced the Flat-Panel Monitors session, stating that the adoption of LCD monitors has accelerated and LCDs will outsell CRTs on a unit basis for the first time in 2004. Even though LCD prices remain about twice those of CRTs, reduced shipping and warehousing costs make them appealing to resellers. As the price gap between 15- and 17-in. models continues to close, much of the growth will be driven by the larger monitors. Chris Connery, from NEC–Mitsubishi Electronic Displays of America, discussed a new approach to running multiple monitors, showing different images from a single graphics adapter with a single connector. Sending image data as packets along a daisy chain of displays allows each monitor to receive its own image data.

The session on Projection Displays also demonstrated how market growth is likely to come largely from the consumer-electronics segment. Sweta Dash cited evidence that projector sales are moving from the corporate to consumer markets, with annual unit sales expected to more than double between 2002 and 2006. Bruce Carskadon of InFocus Corp. described the relationship between television and entertainment projectors as analogous to that between kitchen stoves and barbecue grills; even though there are duplicate functions between the items in each pair, consumers view and use them differently.

Frank Moizio of Texas Instruments drew a parallel between ink-jet printers and projectors; printers were business-only items until prices fell below a certain point and certain features became available, such as affordable photo printing. He sees a similar point coming for projectors, and he predicts that an SVGA projector will be available in 2003 for under $1000. And Dan Zubic of NEC Corp. described the advantages of projectors that support wireless networking.

The corporate-to-consumer shift was evident again in the Mobile Applications presentations. Paul Semenza pointed out that while notebook applications show increased sales – and movement to 15-in. screens as the predominant size – the massive unit growth will be in color mobile phones and color PDAs. Color active-matrix LCDs will continue to be dominant through 2006, making it difficult for novel technologies such as OLED technology to make significant inroads. Bert Keely, architect of tablet PCs from Microsoft Corp., discussed the display and other requirements of tablet PCs. And Marc McConnaughey of ViewSonic pointed to the potential for rapid growth in tablet-PC sales, predicting that models will be available for less than $1000 within 18 months.

Kimberly Allen led the final session, covering OLEDs. The hyperactive interest in recent years has been tempered somewhat by changing economic conditions, but more than 30 companies still have built or plan to build production lines (Fig. 6). In the next 2 years, many of these companies can be expected to drop out, merge, or be acquired by the remaining companies as an industry shakeout takes place. All the same, unit sales are expected to grow from the startup levels of about 4 million in 2002 to more than 180 million in 2006, with communications accounting for about two-thirds of the total.

Bram Roukema of DuPont Displays announced an expansion of the company's already-extensive portfolio of licensing and other technology agreements with a cross-licensing agreement with Universal Display Corp. (UDC). DuPont is also now taking orders for a monochrome customer evaluation kit. Olaf Gelsen of Covion Organic Semiconductors GmbH discussed new developments in OLED materials, including the features required to make ink-jet "printing" of displays practical. One detail is that improvement in ink-jet resolution stopped when it was adequate for end-user printing on paper, but improved accuracy is required for producing displays. And Mike Hack of UDC explained that solid-state displays such as OLEDs have distinct advantages for use on flexible substrates, and top-emitting OLED designs have a larger aperture ratio and better fill factor than bottom-emitting designs.

Turning 20

Preparations are already under way for next year's meeting, which will include recognition of the conference's 20th anniversary. It is planned for December 8–10, 2003, again in Monterey. ■

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conference report

The 10th Color Imaging Conference

CIC celebrated its 10th anniversary with resurgent attendance and a record number of display-related papers.

by Brian Funt and Gabriel Marcu

THE annual Color Imaging Conference (CIC 10) – held most recently in Scottsdale, Arizona, November 12–15, 2002 – continues as the premier technical conference for engineers and scientists working in the areas of color engineering and color science and their application to color products and color-imaging technology. CIC is sponsored by the Society for Information Display (SID) and the Society for Imaging Science and Technology (IS&T), and has a strong international program committee devoted to ensuring a high-quality program through a thorough double-blind review process.

The technical presentations are in a single-track format that allows the attendees to listen to all of the oral presentations. In addition, some papers are presented within an "interactive session" in the form of posters, which enables more in-depth one-to-one discussions between the presenters and the attendees.

Each year, the conference is preceded by a series of tutorials covering the entire range of conference topics. The social events, combined with Arizona's fine November weather, lead to a very pleasant, friendly working atmosphere with a genuine sense of community. There are many opportunities for attendees from academia and industry to meet colleagues from around the world. This year's conference celebrated the event's tenth anniversary with a special session, "Ten Years Later," as well as a birthday party in the evening. The program attracted 265 registrants, up substantially from last year.

Tutorials

On the Tuesday before the start of the technical program, 16 tutorials were offered in the same 2-hour format that has been popular with attendees at past conferences, and they were organized in four tracks: Color Science, Color Management, Digital Imaging, and Applied Color Science. Topics ranged from the human visual system through the ins and outs of the ICC color-management system to spectral imaging and appearance models – with cameras, scanners, and displays covered along the way. Tutorial registration was 270, including many attendees who signed up to take more than one tutorial.

Gabriel Marcu

Fig. 1: *Annette Jaffe (IS&T) and Andy Lakatos (SID) – the general chairs for the first Color Imaging Conference – cut the birthday cake during the CIC 10th anniversary party.*

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One tutorial, "Color in Electronic Displays," taught by Gabriel Marcu (Apple Computer, U.S.A.) – the co-author of this article – gave a comprehensive overview of the color-related issues in the CRT, TFT-LCD, PDP, and OLED technologies.

Keynotes

There were three keynote addresses by internationally renowned speakers. Robert Hunt, Visiting Professor of Color Science at the University of Derby, U.K., compared the capabilities and limitations of the human eye with current camera technology, with the aim of identifying areas of possible improvement. Shree Nayer, Columbia University, U.S.A., described work on a variety of novel imaging devices, including omni-directional and high-dynamic-range cameras. Jean-Marc Fournier, Rowland Institute for Science, described the full-spectrum Lippmann photographic technique and showed one of Lippmann's original photographs. Seeing a 100-year-old original photograph and holding it, heavy with its thick glass ubstrate, is a marvelous experience.

Gabriel Marcu

Fig. 2: The audience at a CIC technical session.

Technical Sessions

The technical papers on displays were presented in oral and poster sessions. The oral session included two papers on TFT-LCD color and one paper on the effects of different RGB color encodings on image processing.

The color performance of TFT-LCDs has undergone a dramatic improvement in recent years. Part of the improvement has been through the introduction of wide-viewing-angle liquid-crystal modes and enhanced monitor design. Although the best TFT-LCD designs have very good color characteristics, there is still a need to understand and model the effects that lead to color additivity errors, hue shifts, and other undesirable characteristics.

The Displays session started with "Color Calibration of TFT-LCDs" by Yasuhiro Yoshida and Yoichi Yamamoto (Sharp Corp., Japan), which provided an overview of mechanisms that contribute to color shifts or color additivity errors. Among these are optical and capacitive crosstalk, and liquid-crystal retardation changes with pixel voltage. These effects were modeled and then incorporated into a hardware color-management circuit.

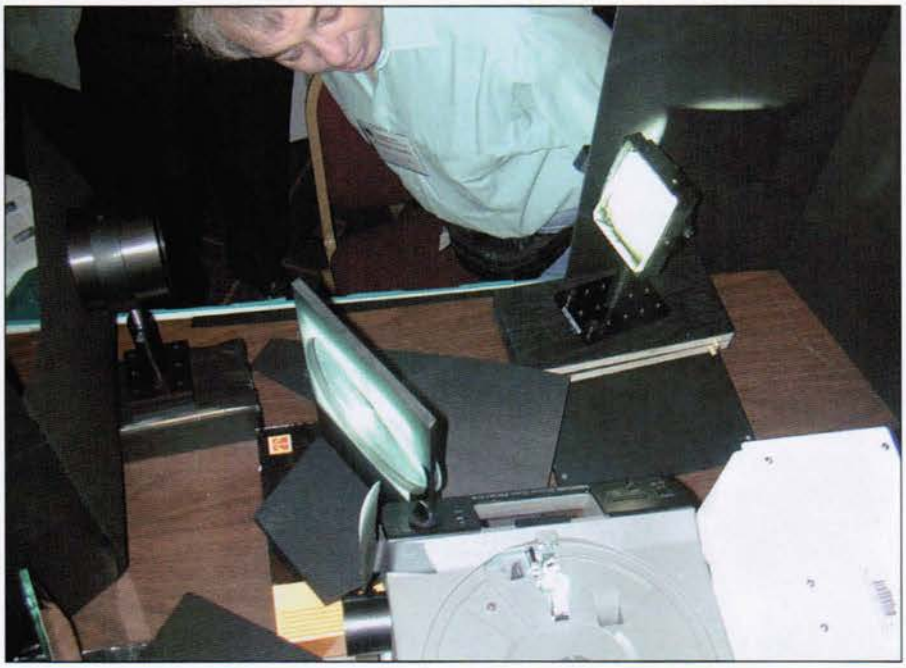
"Masking Model for Accurate Colorimetric Characterization of LCD," by Nobuhiko Tamura and his colleagues from Chiba University, Japan, proposed a masking model in which the color is separated into a gray (R=G=B) component, a secondary component (such as yellow R=G, B=0), and a primary component (such as R, G=B=0). The model is particularly relevant when capacitive crosstalk and light scattering are present in a TFT-LCD pixel array, causing limited contrast ratio.

The other papers on display topics were presented in the Interactive session. In "Color Error from RGB Pixel Stripe Structure," M. Kanazawa and his co-workers from NHK Research Laboratories, Japan, presented an analysis of the effect of the RGB pixel stripe on the displayed color using a modified s-CIELAB method. The results showed that the pixel structure could degrade the image quality even for a viewing distance at which the pixel structure itself is not visible. This occurs because the color difference has a low-frequency component that is detectable by the human visual system. This error can be reduced by a simple signal-processing method.

In "Gray Tracking Correction for TFT-LCDs," Gabriel Marcu and Kok Chen (Apple Computer, U.S.A.) addressed the issues of bluish colorcast, gray non-uniformities, and color banding that arises from time-frame modulation, and the primary shift with the input level in TN portable panels. Their correction method computes the gamma and gray-tracking correction using both the luminance and chrominance responses of the panel in each channel. The colorcast can be removed and a very good consistency of white point with the input signal can be achieved using the 1-D video-card look-up tables available in conventional graphics chips. The poster was awarded third prize at the Interactive session.

Eron Langendijk and Ingrid Heynderickx (Philips, The Netherlands) presented "Optimal and Acceptable Color Ranges for Display Primaries." From comparative studies of color reproduction of natural colors relative to EBU primaries, they concluded that for optimal image quality, the saturation of red, green, and blue should be at least 90%, 90%, and 70%, respectively, while the acceptance threshold for saturation should be 70%, 60%, and 35%, respectively, of the EBU standard.

In "Color Conversion from RGB to RGB + White while Preserving Hue and Saturation," S. D. Lee and his colleagues from Samsung, Korea, confirmed that using the entire RGBW



Gabriel Marcu

Fig. 3: *Jean-Mark Fournier demonstrates his setup to project a rare original Lippmann photograph. Lippmann showed his first pictures, displaying bright colored spectra, in early 1891.*

gamut can improve image brightness without loss of saturation.

Two papers in the Color Appearance Models session dealt with CIECAM02, a new color appearance model soon to be standardized by the CIE. Nathan Moroney (Hewlett-Packard Labs, U.S.A.), speaking on behalf of the technical committee, presented the changes compared to CIECAM97s. These changes include a new linear chromatic adaptation transform, a new non-linear response compression, modifications to the viewing-condition parameters, and changes to the perceptual attribute correlates. Ronnier Luo (University of Derby, U.K.) followed with related experimental results.

The session Ten Years Later reviewed the past decade of the industrial side of the conference with three invited papers. The first was Jim King's "The Color Engineer." He presented the same talk he gave ten years ago to highlight how the field has and has not changed. The second talk was Rob Buckley's "The History of Device Independent Color – 10 Years Later." The third was Todd Newman's account of "Division 8 and the Philosopher's Stone," which described the work of Todd's CIE committees.

In the Color Science session, Scott Fernandez (RIT, U.S.A.) presented "Observer Preferences and Cultural Differences in Color Reproduction of Scenic Images." He concluded that cultural differences in observer preferences are not of practical significance for most applications when a general class of images is used. Observers related to images with faces with a much tighter range of preferences than for images without faces.

In the Applications session, Du-Yong Ng (Purdue University, U.S.A.) gave a presentation on colorimetric imaging of human teeth. In the Printing session, Ján Morovic (University of Derby, U.K.) presented results of a psychophysical experiment on image quality in which observers evaluated image differences induced by the use of one of four gamut-mapping algorithms. Safer Mourad (EMPA) and his colleagues at EPFL presented a model for predicting the reflectance spectra in monochromatic printers. They extended the Kubelka-Munk model to incorporate lateral light spreading within the printed substrate, including fluorescent transmissions.

In one of the Capturing sessions, Paul Hubel (Foveon, Inc., U.S.A.) presented "Eyeing the Camera: Into the Next Century." His technical focus was on how the natural absorption of light by silicon is used to separate the red, green, and blue signals that are collected by the buried p-n diodes. One question that arose was the problem of light saturation in the three-layer design, which does not have any overflow drains. Images were used to show how the "three-layer" sensor produced images free of color-aliasing artifacts.

Interactive Session

This year's Interactive session comprised 33 poster presentations covering the fields of multispectral imaging, capturing, color science, color reproduction, applications, and displays. Intensive discussions with the authors could be observed at many posters. Best papers were selected by attendee voting, and the results were close. The Cactus Award winner (first place) was "Minimal-Effort Characterization of Color Printers for Additional Substrates" by Mark Shaw and colleagues (Xerox Corp., U.S.A.). Thor Olson (Electronics for Imaging) won second place with his paper "The Colors of the Deep Sky." Third place was shared by two papers: "Visualization and Interactive Manipulation of Color Gamuts" by Ivar Farup and his co-workers (Gjøvik University College, Norway) and "Gray Tracking Correction for TFT-LCDs" by Gabriel Marcu and Kok Chen (Apple Computer, U.S.A.).

Next Year

CIC 11 will be held once again at the SunBurst Resort Hotel in Scottsdale, on November 4–7, 2003. The General Conference Chairs are Brian Funt (IS&T) and Gabriel Marcu (SID), and the Technical Program Co-Chairs are Naoya Katoh (IS&T) and Robert Buckley (SID). For current information on CIC 11, which will again be co-sponsored by SID and IS&T, go to http://www.imaging.com. ■

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my turn

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We now have a solid research base. The results of this research will not only support established industries, but will undoubtedly foster new companies having the vision and agility required to move research results quickly from the laboratory to the marketplace. If we abandon this base, we will squander our investment and ensure that we will play an ever-decreasing role in the display industry.

Much better that we should have the vision and dogged determination that is required to succeed in this, or, for that matter, in any other high-technology industry.

John L. West is Director of the Liquid Crystal Institute and the Center for Advanced Liquid Crystalline Optical Materials at Kent State University, P.O. Box 5190, Kent, OH 44242-0001; telephone 330/672-2654, fax 330/672-2796, e-mail: johnwest@lci.kent.edu.

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15 **03**

SEPTEMBER

The 23rd International Display Research Conference (IDRC 2003)

PHOENIX, ARIZONA
SEPTEMBER 15–18, 2003

• An international conference on display research and development aspects of:
• Display Materials (liquid crystals, small-molecule and polymer OLEDs, phosphors, optical compensation films, flexible substrates, etc.) • Display modeling, Design and Processing • Display Systems and Human Interfaces

Dear Mr. Lieberman:

I just read with some humor your "Backlight" essay for the November 2002 issue of *Information Display* magazine. The column used our first polymer-OLED product (the infamous razor) as a "sizzle, no steak" example of new technologies. Quite frankly, while I might have wanted the first product to be the much more elegant passive-matrix display for a mobile phone with full video capability – an application we have also been discussing with OEMs – our Domestic Appliances division was first up to bat. What we did learn in working on it, and you have to give us some credit, is that it showed us that we could get high-yield manufacturing of this new display technology, and meet rigorous customer requirements for delivery and specifications at the same time. We knew what we were doing (after doing research for more than 10 years on OLED), but some guts was necessary to get any product out the door. And again, nobody looked at the shaver as the best product "first," but the fact that the Philishave/ Norelco is a well-known brand name means that we took a risk – and have become infamous for it. So be it – I have a shaver here in my office which I use for demonstrations (never shaved with it yet), and I am waiting to see the new James Bond movie with our shaver in the film. Call me childish, but the pleasure of getting this research out into a first consumer product is a real rarity.

I read your column regularly, and enjoy your perspective on displays – please keep doing what you're doing.

Regards,
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e-mail: eliav.haskal@philips.com

continued from page 2

The display has a 0.1-msec response and does render gray scale. In answer to a question from *Information Display*, Sato said that the polymer network stabilizes the FLC, so there should be no mechanical instability in large displays. Continuing development is focused on improving uniformity and increasing display area.

Next was an interesting autostereoscopic display using, for the moment, an HD LCD panel. The scene is shot with a 2000-line HD camera. Light from the scene passes through a convex lens and then a fly-eye lens on its way to the camera's standard optics. The image from the camera goes to the HD LCD, which has a fly-eye lens in front of it that is the same size as the LCD screen. The 3-D effect is strong, there are multiple "sweet spots" for viewing the image, and the viewer experiences true 3-D parallax in both x and y directions. The depth of focus needs work, and the system sacrifices screen resolution, so an HDTV 3-D system would require a camera and LCD panel with several times the number of pixels normally required for HD, said NHK's Jun Arai. Commercialization of such a system is at least 10 years away, he said.

Our next stop was a change of pace. Instead of a laboratory environment, the location was a small theater with stadium seating. We sat in front of a large 4×7-m screen (320-in. on the diagonal) with a large angular field of view. What we were shown on that screen was an image with 4000 scanning lines, progressively scanned – essentially 16 HDTV screens laid out in a 4×4 matrix. Four 8-Mpixel (3840×2048) LC panels are housed in two projectors whose images are aligned. One of each pair of panels is for RB; the other is for G1 and G2, which are diagonally offset from the RB pixels. The projectors throw 5000 lm at the screen, producing a screen luminance of 50 nits.

We were shown a program consisting of both recorded scenic material and a live feed of a wall-sized curio cabinet with various finely detailed objects, some of which were moving. The recorded material was scanned from 70-mm film, we were told by Senior Research Engineer Masaru Kanazawa, and the system has greater resolution than the 70-mm film. To store 30 sec of programming for the projector requires 40 Gbytes, so they have not recorded extended programs.

The LCoS panels used in the projector deliver good, but not exceptional, color and contrast, Kanazawa said. The effect of that large, detailed image, however, was impressive. The image was combined with a 21-speaker 3-D sound system.

On the other side of one wall was a studio with the curio cabinet and the camera using four 8-Mpixel RGG'B chips. The two greens have slightly different sampling points, but the main reason for the two greens is for their luminance contribution. The camera head, made by Ikegami with lens by Fuji Photo Optical, is connected to a 5-ft.-high equipment rack by an optical cable. The signal is transmitted from the rack to the projector by 16 HD SDI systems. The cabling alone is impressive.

As I returned to Shibuya Station through the mostly melted snow – *via* a ¥3000 cab ride (STRL is quite far from central Tokyo) I thought about the benefits of having industrial research labs that commit themselves to doing long-term research and development. With many of the great American industrial labs now in decline or out of business entirely, it is heartening to see that there are still organizations like NHK with the resources and commitment to do this kind of work.

– KIW

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

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for power-sensitive applications such as cellular phones because the interface circuitry can be inactive until the screen contents change. The next step on the integration trail, said Vrablik, is the integration of digital-to-analog converters and amplifiers into displays, courtesy of enhanced LTPS processes. And further enhancements in the future, he said, will lead to integrated "graphics controllers and other peripheral circuitry."

"The little bit of SRAM in today's LTPS devices allows you to store images and very efficiently address the display by taking advantage of that memory," said Joel Pollack, Vice-President of the Display Products Business Unit at Sharp Microelectronics of the Americas. But with the higher electron mobility and, hence, space efficiency of Sharp's CGS technology, he said, "we can have a lot more memory and not limit the color palette." Sharp has, in fact, given the world an early indication of the great promise of CGS, demonstrating a Z80 microprocessor built with that technology in October 2002. And the ultimate dream of the system-on-glass is a display with not just memory and peripheral circuits, but a full-fledged microprocessor as well.

None of this is to say that the system-on-glass is right around the corner. In fact, I have checked my archives and discovered that I first wrote about the concept in 1992, over ten years ago, and the culmination of the vision is still nowhere in sight. At that time, the display operation at Xerox PARC (later to become dpiX) had already succeeded in integrating polysilicon digital-to-analog converters into a display, but this interim step has yet to be taken by the maker of any commercially available direct-view display.

It is fair to say that LTPS and CGS are both still in their infancy and, based on the technical challenges alone, it will doubtlessly be several years at the least before a system-on-glass becomes viable. "Don't underestimate the challenges of the integration path," said David Mentley, Senior Vice-President at iSuppli/Stanford Resources. LTPS, he said, "has been very tough to tame, far harder than anyone anticipated. Nobody's about to just do a Pentium in polysilicon."

If the technical hurdles for the system-on-glass are high, the business barriers are even higher. But that's a topic for another column. ■

David Lieberman is a veteran display journalist living in Massachusetts.

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In Pursuit of the System-on-Glass

by David Lieberman

We have started seeing some trade-press articles lately about highly integrated displays, by which I mean displays that incorporate much of the support circuitry that traditionally resides in discrete semiconductor packages on a printed-circuit board. The vision of higher integration over time has had various faces, with the ultimate being the so-called system-on-panel or system-on-glass, a long-heralded phenomenon which transforms the display from a system-attached component to the platform for the system itself.

The first step towards higher display integration, of course, has involved drivers, which have been brought closer to the display in the interests of economy in a variety of ways, sometimes utilizing packaged semiconductor drivers and sometimes bare driver dice. These include chip-on-flex (COF) cable, chip-on-board (COB), and chip-on-glass (COG). But the active-matrix revolution in LCDs put an entirely different face on the essence of integration, adding transistors and associated capacitors to the electronics mix but fashioning them on the display substrate itself using thin-film-semiconductor fabrication processes, rather than relying on the mounting of discrete ICs.

Yet another angle on higher integration reared its head in mid-2001 with the advent of the so-called "smart" or "all-in-one" LCD, which incorporates much of the circuitry formerly added to a display after the fact by a monitor maker. This phenomenon has reduced monitor costs by eliminating the printed-circuit board, cabling, and connectors, and it also increased the value of the displays provided by LCD manufacturers.

The vision of the system-on-glass, though, is an active-matrix vision, and one whose fulfillment will require materials with higher electron mobility than is possible with the amorphous-silicon material used by mainstream active-matrix displays. For microdisplays, built on top of single-crystal silicon, the integration possibilities are enormous, limited only by the available real estate of the display. For direct-view displays, the answer is low-temperature polycrystalline silicon (LTPS) and continuous-grain silicon (CGS), which are just now starting to stride down the integration trail.

It has been some time since LTPS took the first step beyond active matrices of thin-film transistors and capacitors, incorporating drivers, latches, and shift registers. The result is a display with far fewer interface connections to the outside world and, according to LTPS boosters, a far more reliable display. "One key point is reliability," said Steve Vrablik, Business Development Director for LCDs at the Display Device and Component Business Unit of Toshiba America Electronic Components, Inc., a U.S. arm of Toshiba Matsushita Display Technology Co., Ltd.

"With notebook computers," he said, "the connections are a major failure point and you can have problems with blocks or lines [of pixels] missing, sometimes due to twisting or deformation [of driver connections]. Looking at our rate of [display] returns since 1998 with LTPS, they are an order of magnitude better than for amorphous," he said.

More recently, companies such as Toshiba and ST-LCD have integrated SRAM into their smaller LTPS LCDs. This represents a power savings

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