MICRODISPLAY ISSUE

Information DISPLAY

SID

July 1999
Vol. 15, No. 7

Official Monthly Publication of the Society for Information Display

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- Microdisplay Partnership
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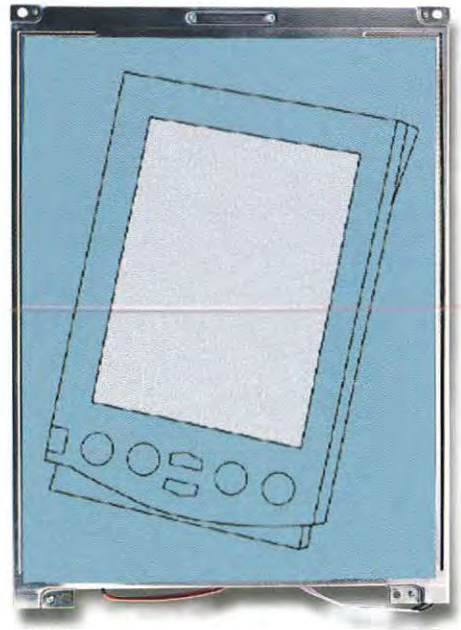

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Circle no. 4

Information DISPLAY

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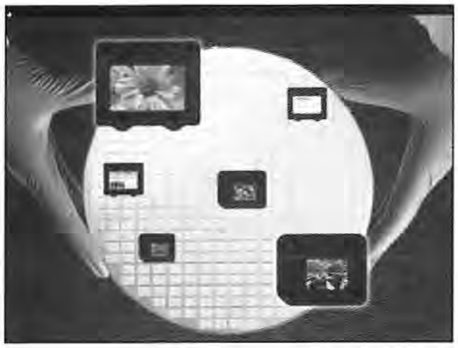
COVER: The promise of lower-cost rear-projection monitors and TV receivers, and high-resolution virtual displays for portable electronics has encouraged a variety of microdisplay technologies and companies. But high-volume customers are not signing purchase orders – not yet.



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Next Month in *Information Display*

Industry Directory Issue

- Directory of the Display Industry
- Successful Display Design
- The Pokemon Incident
- Projection Displays in Aircraft
- CeBIT '99 Report

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editorial

A Lesson in Display Manufacturing and Cross-Strait Diplomacy from Chunghwa Picture Tubes

On March 14, the day that mainland Chinese Premier Zhu Rongji gave his annual news conference for foreign and mainland reporters - a news conference at which he appeared "combative," defended China's deployment of missiles, and "was blunt in condemning mainland Chinese dissidents," according to *The China Post* - I was being warmly received at the Chunghwa Picture Tubes (CPT) plant in Taoyuan, Taiwan.

I thought my hosts might be upset at the political tension between the mainland and Taiwan (and the U.S.), but that was not the case. There was moderate concern, of course, but also confidence that the substantial and rapidly expanding economic ties between the mainland and Taiwan would continue, unimpeded by political inconveniences. Indeed, on that same day, delegates of the mainland National People's Congress approved Premier Zhu's program institutionalizing a stronger role for the private sector.

CPT Vice President T. H. Hsu told this reporter and Fred Kahn (Kahn International, Palo Alto, California) that by the end of this year 40% of the monitors made by Taiwan companies will be made across the Taiwan Strait on the mainland. Historically, he said, CRT production has moved from the U.S. to Japan to Taiwan to Korea. "Now, it is moving to China."

Hsu stressed continuing cross-Strait cooperation. Sixty-five percent of the materials used by the Taiwan display industry now come from Japan, he said. "In the future, we hope to source more material from China."

When he had heard that I would be visiting CPT, David Lieberman of *EE Times* suggested that I ask what CPT would be making in its huge Taoyuan CRT-manufacturing plant in ten years' time. I asked, and Jang-Jeng Liang, LCD R&D Director answered promptly: "In ten years, this CRT plant will be devoted to LCD production and manufacturing equipment (with some CRT production remaining). Most CRT manufacturing will go to China and Malaysia."

LCD production at Chunghwa Picture Tubes, the world's largest manufacturer of color display tubes?

LCDs at CPT

Although the sweep of Liang's answer surprised me, the fact that CPT was becoming a serious manufacturer of TFT-LCDs was no surprise at all. In fact, the opportunity to tour CPT's nearly completed Generation 3 AMLCD production line - which had been generously arranged by CPT's Hsing-Yao (Jimmy) Chen - was a major reason for my visit to Taoyuan.

So Fred Kahn and I were shown the first 15-in. AMLCD made in Taiwan, outfitted with two-layer "bunny suits," and escorted onto the plant floor, which was about one month from start-up at the time - the first Gen 3 plant to be completed in Taiwan, said Chen. The plant consists of three floors, each of which measures 180 × 55 m (plus a fourth floor for offices and administration). The total plant investment will wind up being about NT20 billion, or about 660 million U.S. dollars. The plant will produce 14.1- and 15.0-in. panels 4-up on 550 × 670-mm substrates, with a capacity exceeding 100,000 displays per month.

continued on page 34

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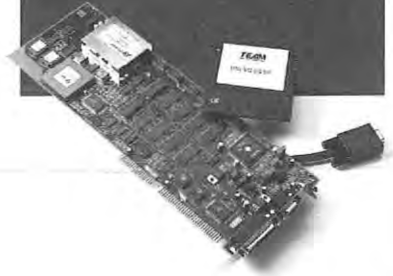

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Circle no. 5

the display continuum

Crossing the Threshold ...

by Aris Silzars

We've all done it – at exhibit booths, at author interview sessions, in private suites, and even during visits to company facilities. It's something that we display types never tire of doing, for which we never turn down an invitation, and which on rare occasions brings us great excitement. After all, encounters with the latest and greatest developments in display technology are what keep us stimulated and what we live for. And perhaps for a few, these occasions provide a modest calibration of our own incomparable efforts.

Thus, when we're shown the latest LCD desktop monitor or other new display, we immediately get our noses as close as we can and look for – what's wrong with it! Are there missing pixels? How bright is it? Are the colors off? How good is the contrast? What is the viewing angle? In the approximately 30 msec that it takes our well-trained visual systems to answer these basic questions, we decide if the technology is worthy of further scrutiny. If it is, we then quickly move on to that most critical of inspections: the up-close visual inspection of the entire display surface, with extra attention to all the corners. For those of us who are significantly nearsighted, this process of literally "sticking our noses into other people's business" is a wonderfully satisfying experience because at the 10–15 cm viewing distance we win the defect-finding contests every time.

This examination is typically followed by knowledgeable nods to colleagues nearby with confirming comments such as: "Well, after a few more years of development this technology *may* have some merit." Or perhaps: "Did you see those missing pixels and the defects from the misaligned spacers?" "And did you notice the contrast? It couldn't have been more than 10:1. I just don't believe what the marketing guy was saying about turning the brightness down to match the lighting in the exhibition hall."

Time passes. The following year we look again. This time there are fewer defects and the display looks better, but it still isn't very bright and the resolution isn't all that we would like to see. Progress has been made, but it still doesn't look like a real product – one that could compete with the latest CRT display.

Another year or two goes by. Once again, the same technology can be found in the exhibit hall, but now there seem to be more booths, more companies, and more products using this approach. This time when we take a closer look something is very different. This time there are no noticeable defects. The brightness and contrast look good. The displayed images of wildflowers waving in the gentle spring breeze are surprisingly lifelike and we can almost feel the coolness of the water in the babbling brook. Quite remarkably, this display now appears to be "good enough." After years of "future potential," it had quite abruptly "arrived."

With such seemingly slow progress during all those earlier years, how could such a spectacular leap have occurred so quickly? An examination of the technical data indicates the exact opposite. There has been no dramatic leap in performance – just steady progress. Then how can we explain this perceptual disconnect?

continued on page 32

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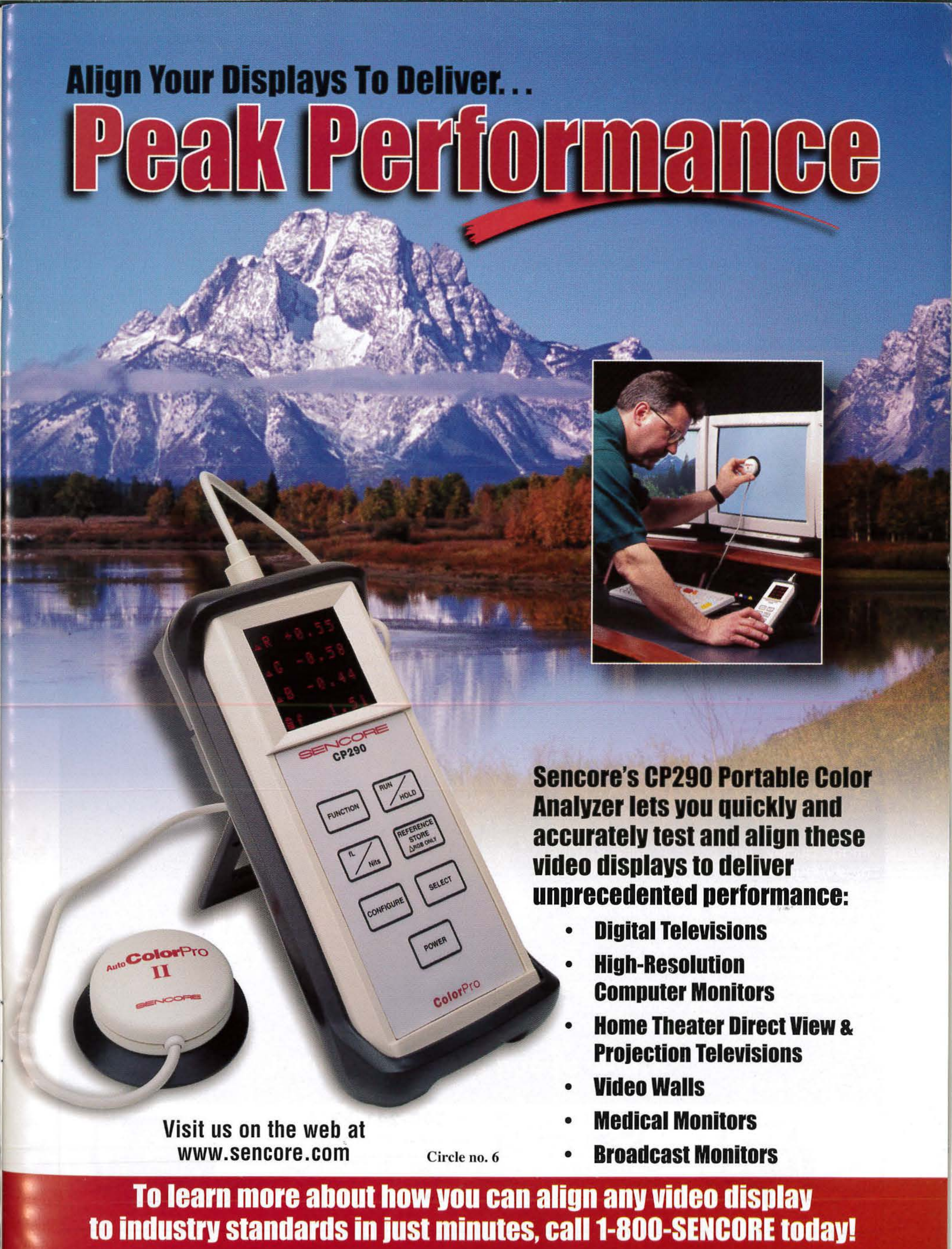
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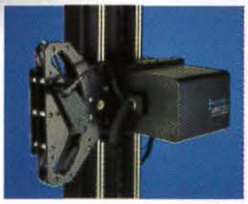

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Circle No. 3

If Microdisplays Are the Answer, What Is the Question?

Manufacturers are making tiny, highly effective windows on the high-tech world – but the quantities are not yet large enough for system makers to embrace the mini-devices for high-volume applications.

by Chris Chinnock

OVER THE PAST FEW YEARS, people have been paying more and more attention to microdisplays, which many in the industry define as flat-panel displays with diagonal dimensions under 1.5 in. (although the author of this article includes projection panels up to 3 in.). There is a good reason for all the buzz. These devices may soon find uses in high-volume projection products and open up new opportunities for personal display products that feature a virtual image. With dozens of players and almost as many microdisplay technologies, the big question is "Is there room for everyone?" As these new technologies mature and come to market in products over the next few years, their individual merits and pitfalls will become more obvious.

Microdisplays are small by definition, but they also have very high pixel densities, typically more than 700 lines per inch (lpi), with many displaying more than 1000 lpi. SVGA and XGA displays less than an inch on the diagonal are now available from multiple sources in multiple technologies. What distinguishes a microdisplay from a small direct-view display is the use of magnification. As a result, the products in which they are used are

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Digital Reflection

Fig. 1: *Digital Reflection's prototype 50-in. rear-projection HDTV display features a three-panel LCOS engine.*

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generally divided into two broad segments: projection and virtual displays.

The Big Picture

A market already exists for front projectors using microdisplays, which makes it easier for new microdisplay technologies to find a foothold, although they still must demonstrate some advantage over incumbent technologies. Polysilicon AMLCDs from several Japanese suppliers and the Digital Micromirror Device (DMD) from Texas Instruments remain the devices to beat for price and performance.

Perhaps the most promising microdisplay technology is reflective liquid crystal on silicon (LCOS). This technology offers potential cost improvements, perhaps opening up projection products into entirely new categories. Just over the horizon, for example, are a number of rear-screen projection systems mainly targeted for large-format computer monitors (20–30 in.) and rear-projection HDTV (over 40 in.). Prototypes of these products are being shown now, with commercial products likely before the year is out (Fig. 1). With current HDTV sets selling for $6000 and up, rear-screen HDTVs using microdisplays priced in the $2000–3000 range could do very well indeed. There is even talk about microdisplay-based monitors below $1000. Such products could do very well, and microdisplays could have a huge impact on the display, computer, and TV industries.

High-Tech Peep Shows

A number of product concepts rely on a virtual image for personal display products. A large virtual image that offers the same visual impact as a desktop-computer monitor is a compelling feature, but there are many unanswered questions. Perhaps the biggest issue is the so-called "use model."

Virtual displays require that the display module be fairly close to the eye. One accepted use model is a viewfinder, such as that found in camcorders and cameras. Replacing optical or low-resolution viewfinders with high-resolution microdisplays is one option, but the viewfinder must be very low in cost – less than $30 – to be competitive.

An extension of this viewfinder concept may be coming in the form of a cellular phone with a high-resolution display. Within 3–5 years, wireless phones may have sufficient bandwidth to support high-speed Internet browsing, e-mail, fax viewing, and even video conferencing (Fig. 2). Throw in GPS location services, and some novel products could soon emerge.

A second use model could be called "head-worn." Virtual-reality headsets fit into this paradigm, as do headsets for wearable computers. What is not clear is whether users will accept such designs, but, with improved designs and compelling applications, this use model might take hold. Big opportunities

Siliscape

Fig. 2: This mock-up of a cellular phone contains an SVGA color-microdisplay eyepiece from Siliscape.

could exist for a headset that plugs into a notebook computer or into a portable DVD player for entertainment; the result could be reduced overall size and increased privacy.

Other use models include head-up displays, as in automobiles and aircraft cockpits, or the replacement of arm's-length direct-view displays by microdisplays. These two opportunities seem less likely to succeed in the near term, however.

Many of the platforms targeted for microdisplays are high-volume consumer products where cost is critical. Prices of $50 for 0.5-in. SVGA LCOS displays are being quoted for volume quantities, but no one is known to be making them in large volumes with high yields for delivery at this price. The challenge now is to prove that the new microdisplay devices can be manufactured in volume and at low cost, while meeting the performance requirements of the market.

This will be a critical year for many emerging microdisplay technologies, so let's take a look at the contestants. We'll discuss four primary technology approaches that can be used to create projection- or virtual-display-based systems: transmissive, reflective, and emissive microdisplays, and scanned systems that use laser or LED light sources (Table 1).

Table 1: Major Suppliers of Microdisplays (Courtesy of *Microdisplay Report*)

Approach	Technology	Company	Location	Applications
Transmissive	Polysilicon	Sony	Tokyo, Japan	Virtual and Projection
		Matsushita	Osaka, Japan	Virtual and Projection
		Epson	Torrance, CA	Virtual and Projection
		Sarif	Vancouver, WA	Virtual and Projection
		Sharp/SEL	Kanagawa, Japan	Projection
		Sanyo	Tokyo, Japan	Virtual and Projection
	x-Si	Kopin	Taunton, MA	Virtual
Reflective	MEMS	Texas Instruments	Dallas, TX	Projection
		Daewoo/Samsung	Seoul, Korea	Projection
	LCOS	Colorado MicroDisplay	Boulder, CO	Virtual and Projection
		Displaytech	Longmont, CO	Virtual and Projection
		Three-Five Systems	Tempe, AZ	Virtual and Projection
		National Semiconductor	Santa Clara, CA	Virtual and Projection
		Varitronix	Hong Kong, China	Virtual and Projection
		MicroPix	Dalgety Bay, Scotland	Virtual and Projection
		Siliscape	Sunnyvale, CA	Virtual
		IBM	Yorktown Heights, NY	Projection

Transmissive Microdisplays

The most mature microdisplay technology is high-temperature-polysilicon (HTPS) active-matrix liquid-crystal displays (AMLCDs). Leaders such as Sony, Epson, and Sanyo have developed this technology for use in front-projection systems and virtual-display-based systems such as camcorders. In the fabrication of HTPS microdisplays, amorphous silicon is deposited on a quartz substrate and recrystallized into polysilicon through a high-temperature annealing process.

The benefit of polysilicon microdisplays is that they allow display drivers to be fabricated on the same substrate, but their electrical performance is not generally good enough to provide more complex electronic circuitry on the display.

Low-temperature-polysilicon (LTPS) processing, using laser annealing, is now being done on glass substrates, thus lowering costs. So far, although LTPS devices have been used for small direct-view displays in camcorders and digital still cameras, they have not been used for high-density viewfinders. Many industry analysts view polysilicon microdisplays as a mature technology with limited prospects for dramatic improvements. As manufacturers move to higher-density microdisplays, aperture-ratio problems increase rapidly because there are limits to how small the on-screen transistors and address lines can be made. Yet suppliers have managed to keep squeezing more performance out of this technology. The use of a microlens array over the pixel matrix, for example, has been used successfully to boost light-transmission efficiency.

In another sign of innovation in the polysilicon camp, Sharp and partner Semiconductor Energy Labs have developed their so-called continuous-grain-silicon (CGS) process. It boosts carrier mobility to about half of that obtainable in single-crystal silicon, which is far higher than alternative polysilicon approaches. The low-temperature process is suitable for glass substrates, too, and allows the incorporation of more onboard circuitry along with high aperture ratios.

At last January's Consumer Electronics Show, Sharp showed a 60-in. rear-projection HDTV that will probably appear as a commercial product before the end of the year. Specifications and pricing have not yet been determined, but it was definitely the brightest rear-projection system on the show floor. The prototype used three 2.6-in. XGA panels.

Kopin Corp. is now using a Taiwan fab to help with manufacturing and can now offer quarter-VGA-resolution (QVGA) LCDs. In the Kopin approach, both the on- and off-screen electronics are fabricated on a silicon-on-insulator (SOI) wafer and transferred to glass. Support ASICs for driving the display – which has been a bit of a hurdle for many new microdisplay technologies – are now available from Motorola, Sound Vision, Fuji-Film Microdevices, and Sierra Imaging.

Table 1: Continued

Approach	Technology	Company	Location	Applications
		Victor Co. of Japan	Kanagawa, Japan	Projection
		S-Vision	San Jose, CA	Projection
		SpatiaLight	Novato, CA	Virtual and Projection
		MicroDisplay Corp.	San Pablo, CA	Virtual and Projection
Emissive	VF on Si	Display Research Labs	Los Altos, CA	Virtual
		Ise Electronics	Mie, Japan	Virtual
	AMEL	Planar	Beaverton, OR	Virtual
	OLED on Si	FED Corp.	East Fishkill, NY	Virtual
	OLEP on p-Si	Cambridge Display Technology	Cambridge, UK	Virtual? Direct-View
		Seiko-Epson	Tokyo, Japan	Virtual? Direct-View
	OEL on p-Si	Sanyo	Tokyo, Japan	Virtual Direct-View
	FED	Micron Display	Boise, ID	Virtual
Scanning	1-D/2-D MEMS	Microvision	Seattle, WA	Virtual
		Nippon Signal	Tokyo, Japan	Virtual? Projection
		MicroOptical	Boston, MA	Virtual
		Silicon Light Machines	Sunnyvale, CA	Projection

Reflective Microdisplays

Probably the hottest of the microdisplay technologies are the reflectives: liquid crystal on silicon (LCOS) and microelectromechanical systems (MEMS).

The DMD developed by Texas Instruments is the best known and most successful MEMS microdisplay. This device is fabricated directly on silicon and is machined to create an array of tiny mirrors that flip from one position to another with an applied voltage. DMDs have met with great success in the ultra-portable and large-venue segments of the front-projection market.

TI is now moving to establish DLP projection engines with SXGA resolution for electronic cinema and HDTV devices with 1280 × 720 resolution, but cost is an issue. Extending established design rules from the XGA device to SXGA, for example, produces a display that is about 1.1 in. on the diagonal. But since the display cost is proportional to area, TI is thinking about shrinking the size of the pixels. Recently, the company revealed they are now planning an XGA device that is 0.7 in. on the diagonal, the same size as their current SVGA device.

A new entrant, Daewoo Electronics, has also shown a MEMS prototype projector. Daewoo's chip – unlike TI's – has analog response. But, under pressure from the Korean Government and the International Monetary Fund, Daewoo's electronics unit may be swapped for Samsung's automotive unit, leaving further development prospects unclear.

LCOS technology has attracted the largest number of players so far. Here, the active-matrix control circuitry is fabricated as CMOS electronics in a silicon foundry. A second facility is then used to apply the liquid-crystal layer. LCOS microdisplays can use 85% or more of their surface area to reflect light.

Manufacturers are differentiating their products in the materials, architectures (digital or analog), and business models they have employed for fabrication. For example, Displaytech and MicroPix are using a ferroelectric LCD, while others use variations on twisted-nematic (TN) materials. Siliscape and S-Vision are proponents of an all-digital backplane, while most of the others have chosen an analog approach. Analog works well if the signal source is already analog – such as a computer-monitor signal or NTSC video – but digital approaches have advantages for direct coupling to processors in, for example, digital computers or cellular phones.

On the manufacturing side, some companies are choosing to contract with existing CMOS and LCD factories to make microdisplays to their specifications: a virtual manufacturing model. Others – such as Three-Five Systems, S-Vision, Varitronix, and Displaytech – have their own LCD fabrication and assembly facilities, but outsource the CMOS fabrication. Three-Five Systems can produce 400,000 SVGA microdisplays per month if they run their factory at full tilt.

The really big promise of LCOS displays is their potential for adding lots of functionality to the CMOS backplane while retaining their low cost and small size. (Think of them as ASICs with an LCD on top.) Microdisplay Corp. has already shown devices that incorporate digital and analog interface electronics, but the company says this is just the beginning. The year 1999 will be a major test of these companies as production ramps up and the first products reach market (Fig. 3).

Emissive Microdisplays

The emissive-microdisplay category actually includes several technologies. Some approaches use a silicon backplane, while others incorporate an LTPS matrix on glass. The emissive layer is then deposited on top of the backplane, and can consist of electroluminescent (EL) materials, phosphors, or organic polymers.

Planar is now in production with a VGA monochrome version of their active-matrix electroluminescent (AMEL) microdisplay. Kodak has licensed both FED Corp. and Sanyo to develop organic-EL-on-silicon and polysilicon substrates, respectively.

Colorado MicroDisplay

Fig. 3: Their tiny size and high resolution make reflective LCOS microdisplays well-suited for both projection- and virtual-display applications.

Vacuum fluorescent (VF) technology uses electrons - sometimes from a wire filament - to excite phosphors. The vacuum-fluorescent-on-silicon (VFOS) process being developed by Display Research Labs, for example, is being targeted as a direct replacement for camcorder displays. The company thinks it can make 300 × 400-pixel devices for less than $30 each.

Another emerging display technology is organic light-emitting polymer (OLEP). Lower-resolution direct-view OLED displays are currently in an early commercialization phase, but active-matrix organic light-emitting polymer (AMOLEP) microdisplays are also under development. FED Corp. has a new manufacturing line to make SXGA OLED devices for virtual-display applications.

Finally, field-emission displays (FEDs) are under development as microdisplays. But Micron Display is the only major proponent of this approach, and support for applying the technology to microdisplays appears to be waning.

Scanned Systems

Miniature mechanical scanning systems, in addition to the other two-dimensional microdisplays discussed so far, can also be used to create both projected and virtual images. They typically rely on red, green, and blue lasers - or LEDs - as image sources, and use a galvanometer to perform either 1-D or 2-D scanning. Omron scans red, green, and blue linear LED arrays to produce a full-color 2-D image, for example.

But the technology with the most promise is based upon MEMS scanners. Unlike MEMS microdisplay concepts, which consist of a full 2-D array of light modulators, MEMS scanners consist of either a linear array or a single-element modulator.

Silicon Light Machines has developed a scanned linear array in a 1 × 1080 arrangement, with each pixel containing several deformable ribbons. Alternating ribbons are moved downward to cause interference with incoming light and modulate the reflected signal. With a three-laser system, the company can produce a full-color HDTV.

Single-element MEMS devices are also under development. These consist of mirrors that can pivot in two orthogonal directions. A modulated laser beam can now be scanned in two directions from a single MEMS device, but development is still in the early stages.

With a variety of technologies and many potential applications, there is probably room for many of the current players - except, perhaps, for LCOS displays. End-product volumes will have to develop quickly to support the large number of players in this segment, even if all of their technology implementations prove equally worthy. Otherwise, it is likely that some of these companies won't be able to last until the markets finally arrive. ■

Circle no. 12

Circle no. 13

Circle no. 14

Providing the Missing Links

Just having a good display doesn't guarantee success. Displaytech and Hewlett-Packard are attracting customers by providing the missing links in the microdisplay technology and supply chains.

by Haviland Wright, Mark Handschy, and Bob Myers

THE PROSPECT OF MINIATURE DISPLAYS has engendered lots of industry excitement in recent years. In many large computer hardware manufacturing companies today, microdisplays are under active consideration as replacements for existing devices and as candidate displays for entirely new types of applications (Table 1). Microdisplays often offer substantial advantages over older technologies, and we are convinced that microdisplays based on ferroelectric-liquid-crystal (FLC) technology are capable of delivering even greater gains (Table 2).

But practical working microdisplay devices are still rare, and very few are yet being incorporated into consumer products with substantial markets. The successful transition from microdisplay-technology R&D to mass-market consumer products will be a critical milestone in the maturation of the display industry as a whole. But this is a chasm that will not be crossed without facing some genuinely tough challenges, not all of which involve technology *per se*. Displaytech and the Hewlett-Packard Company have agreed to jointly design, manufacture, market, and distribute reflective microdisplay components and subsystems. We feel that our combined resources will help overcome these obstacles.

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Daunting Hurdles – and Solutions

As Displaytech's liquid-crystal (LC) technology moved from the laboratory into commercial microdisplays, a number of component-design and volume-manufacturing issues had to be resolved. While widely distributed direct-view LCD products provide some guidance, many microdisplay requirements call for unique solutions. Microdisplays need to deliver the same resolution formats as direct-view displays – from quarter-VGA (320 × 240) up through SXGA (1280 × 1024) to UXGA (1600 × 1200) and HDTV (1920 × 1080) – while consuming a minimum of

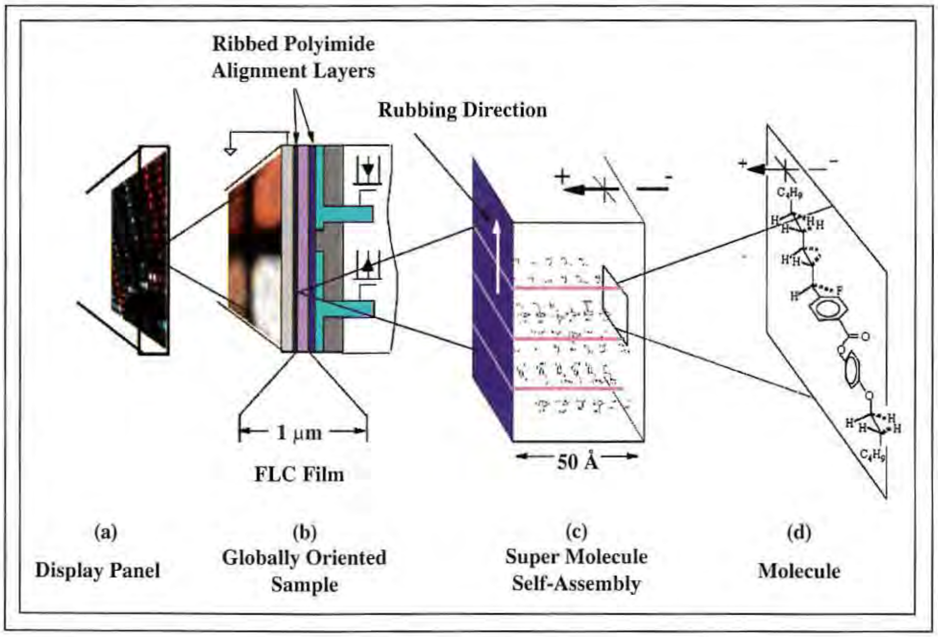

***Fig. 1:** Drawings at different scales show different aspects of Displaytech's approach to FLC microdisplay design.*

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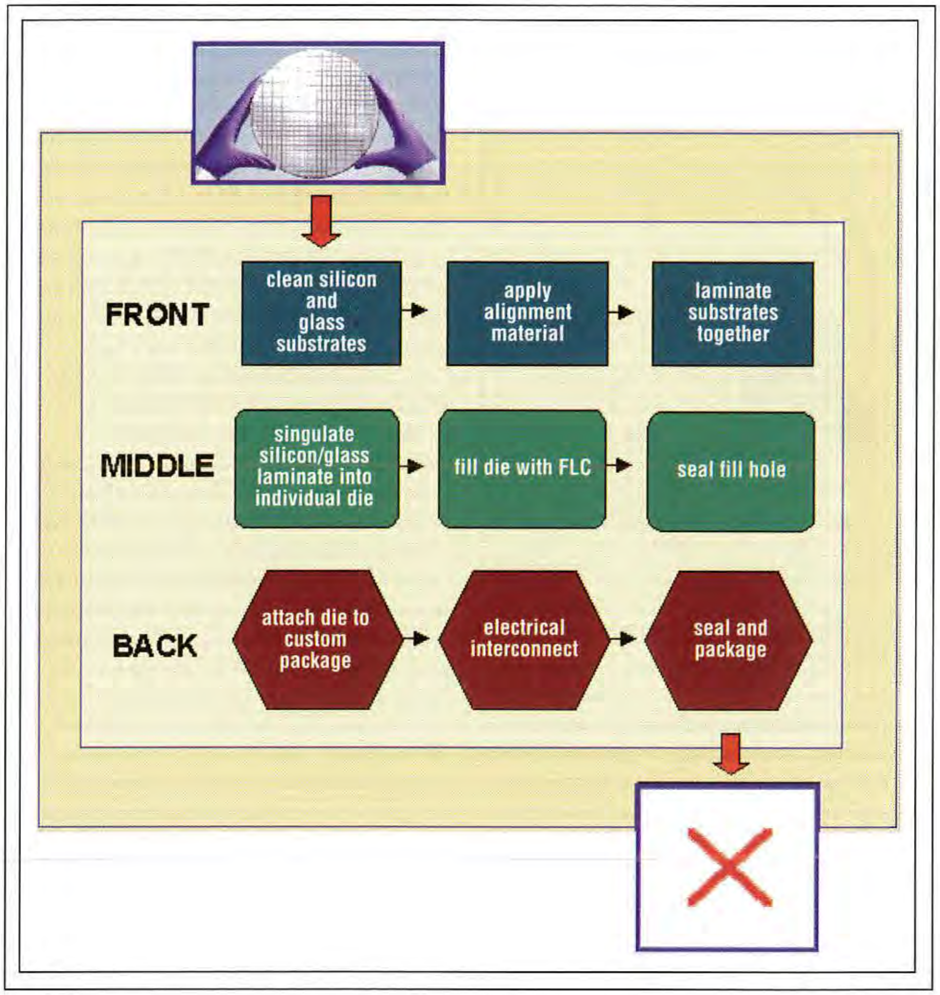

Fig. 2: The manufacturing flow of Displaytech's microdisplays starts with CMOS wafers fabricated in a standard process, but with optimized cross-die planarity and enhanced last-metal reflectivity. The wafers enter the manufacturing line at the "front end," where they are joined with glass wafers to make wafer-scale "laminates.".

expensive silicon real estate. Minimizing pixel size clearly minimizes microdisplay costs.

Device Design

A complete microdisplay has the dimensions of a silicon chip, *i.e.,* a diagonal ranging from a few millimeters for a viewfinder device up to nearly an inch for the largest projection-display panel [Fig. 1(a)]. Higher magnification reveals details of Displaytech's approach to making such a device [Figs. 1(b)–1(d)]:

- LC material is confined to a 1-mm-thick layer between a glass window and a silicon integrated-circuit backplane.
- Polyimide layers applied to both the silicon and glass substrates align the LC in a chosen direction.
- The LC is driven by underlying integrated circuitry through aluminum pads on the upper surface of the backplane, which serve as both pixel mirrors and drive electrodes.

At still higher magnification, structural features of the LC can be seen. The LC material is ferroelectric. The reversal of its polarization in response to electric fields created by logic-level voltages applied to the pixel pads generates an in-plane reorientation of the optic axis, which is the principal light-modulation effect. The ferroelectric polarization arises from the ordered orientation of the dipole moments of individual molecules, which is shown at the highest magnification.

The device geometry shown in the figure has a number of advantages for microdisplays. The relatively thin LC cell gap permits the realization of small-pixel pitches. The thin gap minimizes the deleterious effects of fringing electric fields, and small pixels function without any of their aperture being obscured by disclination defects. The in-plane optic-axis switching gives high contrast even at large optical incidence angles, which provides good performance in light-efficient optical systems as fast as $f/1$. The fast-switching FLC material is compatible with low drive voltages, enabling single-panel field-sequential-color displays while allowing the backplane to be fabricated in a variety of readily available standard CMOS processes.

Manufacturing

While Displaytech's and HP's process for microdisplay production draws heavily on conventional silicon-fabrication, LCD-manufacturing, and electronic-packaging processes, it also includes some critical differences. CMOS wafers fabricated in a standard process, but with optimized cross-die planarity and enhanced last-metal reflectivity, enter the Displaytech manufacturing line at the "front end," where they are joined with glass wafers to make wafer-scale "laminates" (Fig. 2). At this stage of the process, the wafers are cleaned, a rubbed alignment layer is applied, the cell gap is set, and a perimeter seal is applied around each individual display. This part of the processing takes place in a clean room, and is similar to conventional LCD processing. Special techniques are used, however, to deposit perimeter seals that – even with 1-μm cell gaps – do not consume excessive silicon real estate.

In the "middle" of the line, the laminates are singulated, *i.e.,* separated, into individual display dice, filled with FLC material, and

Table 1: Displaytech Target Markets

Replacement Technology	New-Generation Devices
Television	Video telephones
Monitors	Personal GPS
Digital cameras	Wearable computers
Camcorders	Video viewers

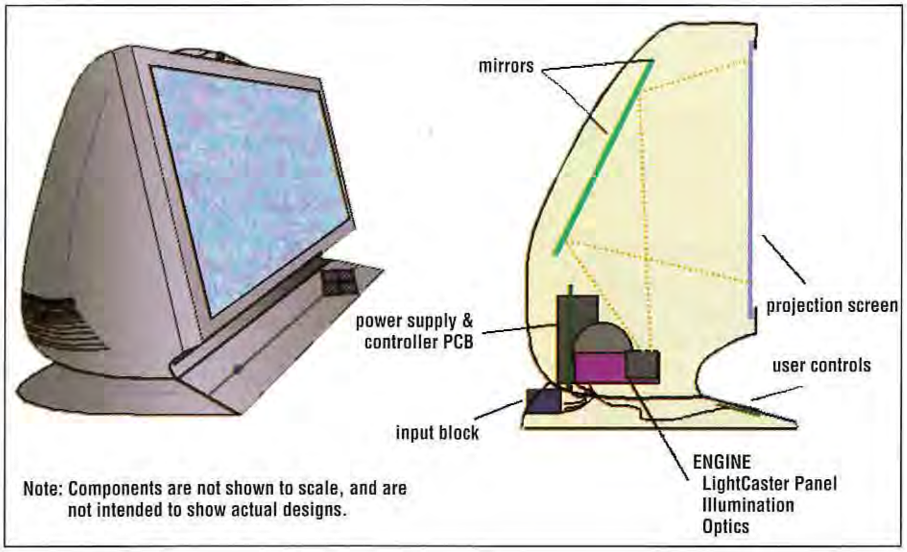

Fig. 3: Ferroelectric-liquid-crystal (FLC) microdisplays have the switching speed to make inexpensive single-panel 24-bit-color rear-projection monitors possible.

sealed. Again, standard LCD processing techniques and equipment are used. Since the display cell-gap spacing is already set, this part of the process is not particularly sensitive to particle contamination, and does not need the very clean environment required at the front of the line. More information on cell separation can be found in a recent paper by Displaytech and Villa Precision ("Miniature Display Cell Separation," Stanford Resources' 15th annual Flat Information Displays Conference, December 2–3, 1998).

Displaytech develops its FLC materials especially for microdisplay applications, and formulates them to operate at the low drive voltages available from CMOS circuitry. Materials optimized for operation at ±2.5 V (5 V CMOS) and at ±1.65 V (3.3 V CMOS) are available today, and materials optimized for operation at ±1.25 V (2.5 V CMOS) are under development.

The final steps carried out on the "back" of the line are exactly the same as the die-attach and interconnection steps carried out by any IC-packaging operation. Careful choice of materials is adequate to ensure that, even with standard package-assembly equipment, good display quality is maintained throughout the back end.

Standards Would Be Nice

As with any new technology, the development and acceptance of industry standards will greatly advance the growth of the microdisplay market. Recognizing the growing importance of microdisplays and the new products and applications they enable, the Video Electronics Standards Association (VESA) recently started a new special interest group to discuss the needs for standards in the area. The VESA group, which held its first meeting in conjunction with Display Works 99 in San Jose this past February, is expected to recommend several standards-development efforts.

Monitor interfaces – including the recent VESA "Plug and Display" standard, which supports both digital and analog video interfaces – attempt to be as independent of specific display technologies as possible, but new standards have become critically necessary in other areas. For example, microdisplay technology will make a wide range of personal display products practical in both consumer and professional markets. These include head-mounted, or "eyeglass," displays for use with personal digital assistants or personal DVD players, as well as miniature displays for fax or e-mail viewing. But no suitable interface standards exist for such products today. Standard interfaces for personal displays will have to provide both the bandwidth required for full-color video transmission and power for the display itself, using small flexible cables and connectors designed to withstand the rigors of portable use.

At least initially, standardization of the interface to the display device itself is unlikely because the drive signals to the microdisplay vary considerably with the specific technology of the device. However, a common feature of many microdisplay types is their reliance on field-sequential color rather than the more common parallel RGB drive. While defining standards for the transmission of field-sequential video is a relatively simple task, it will be essential for broad acceptance of the technology.

Electronics

Just producing microdisplay components does not provide a complete solution for manufacturers planning to incorporate these devices into products. At a minimum, many microdisplay designs will require conversion of the more typical parallel RGB video into field-sequential drive, and a number of microdisplay technologies rely on temporal and/or spatial modulation techniques in order to obtain their "gray-scale" capabilities. The FLC microdisplays offered by Displaytech and HP are a good example of this. The very rapid switching speed of the FLC material permits high-quality images with full 24-bit color, but unique drive techniques are required to realize this performance.

In examining the requirements for microdisplay drive electronics, we can divide dis-

Table 2: Microdisplays Based on Ferroelectric Liquid-Crystal Technology Are Capable of Delivering Significant Advantages over Older Technologies

Microdisplay Advantages	FLCD Advantages
Small chip/Big image	Designed for projection and personal displays
Low cost	Application-specific FLC materials
Resolution through IC design	Full motion, full color, flicker-free video
Light weight	Broad operating temperature range
Small form factor	Smallest pixels, multiple resolutions

play control into two major groups of tasks. The first group is the "front end," which is independent of the display technology in use. The second group is the "back end," where image information is transferred into the drive and control signals specific to the particular display are applied. The "front end" tasks – which include such functions as image format, frame-rate conversion, and generating on-screen displays (OSDs) for user control information – are already addressed by a number of commercially available solutions. However, the requirements for driving the microdisplay panel itself are usually unique to each particular microdisplay technology, so generic solutions are not readily available.

To address this need for FLC microdisplays, Displaytech and HP will produce driver ICs to support a wide range of applications, from large-screen projection displays to near-eye applications such as viewfinders and "eyeglass" displays. The goal is to provide a consistent, standard interface to the microdisplay system regardless of image format, specific panel drive requirements, or whether the display uses one or three panels. Using such a generic interface will permit the microdisplay system to be used with any of a wide range of existing "front-end" controllers and display-interface designs. Later, as microdisplay use becomes more widespread and user requirements become better defined, some of the "front-end" functions may be integrated with the panel drive, reducing overall system complexity and cost.

Personal Displays

Personal displays show the user images on a microdisplay through magnification optics that normally require the display system to be close to the user's eye, like a peephole viewfinder on a camera. Interest in personal displays reflects the ongoing product-design trend towards mobile information and entertainment devices. Some of these devices can be seen in the market today: cellular phones, personal computers, information managers, and digital cameras have become smaller and more capable.

While smaller and lighter designs enhance most functional areas in these products, they often reduce the effectiveness of built-in direct-view information displays. Personal displays offer a way out of this dilemma, combining the image quality of a desktop monitor with the size, weight, and power consumption required for a mobile product.

In the case of cameras, the shift from surface-mounted low-resolution LCDs to a high-resolution peephole viewfinder does not challenge users with an unknown user model. Such cameras could be extremely small. Under the normal-use model – in which the camera is used intermittently rather than continuously – they would consume dramatically less power than digital cameras today and offer battery life measured in months rather than minutes. Peephole viewfinders also have the advantage of being usable in all lighting conditions.

Personal display design for cellular phones, computers, and information managers is particularly challenging because of the lack of established user models. The seriousness of this challenge is evident in the marketing results of the head-mounted, helmet, and "eyeglass" displays that have been offered to consumers so far. The concept certainly has appeal: access any form of digital information anywhere, at any time. Faxes, e-mail, Web sites, digital photos, spreadsheets, and electronic documents can be seen with full fidelity, extending the mobile-communications model to embrace the full range of business and personal communications modalities. The question is whether consumers will appear in public sporting the necessary gear.

Personal video viewers are perhaps the most promising opportunity for wearable microdisplay designs. Indeed, portable DVD players seem to beg for wearable viewers.

Projection Applications

In addition to near-eye uses in which the display is directly viewed through magnifying optics, reflective microdisplays can also be deployed in large-screen applications that have traditionally been the domain of the CRT. Here, the FLC microdisplay's image must be projected onto a suitable screen, and this calls for significant amounts of light to be handled by the device. Achieving sufficient optical throughput while still preserving good image quality is the primary challenge in developing projection displays to compete with established technologies.

Reflective microdisplays for projection applications generally fall into one of two main categories: those that rely on an electromechanical effect to modulate light and those that, like conventional direct-view LCDs, make use of polarization. An example of the former is the Digital Micromirror Device (DMD) from Texas Instruments; the latter category is primarily made up of liquid-crystal-on-silicon (LCOS) devices (including the FLC microdisplays from Displaytech and HP).

At first glance, electromechanical devices would seem to have the edge in projection applications because they do not suffer from the efficiency losses arising from the polarization required in LC devices. However, achieving very high resolutions has not been practical thus far with electromechanical devices, owing to the relatively large pixels they must employ.

In contrast, LCOS devices provide the much smaller pixel size required for projection applications that seek to compete with direct-view display technologies, such as rear-projection television displays and desktop PC monitors. Pixels of 10 μm and under have already been achieved. Since die size, rather

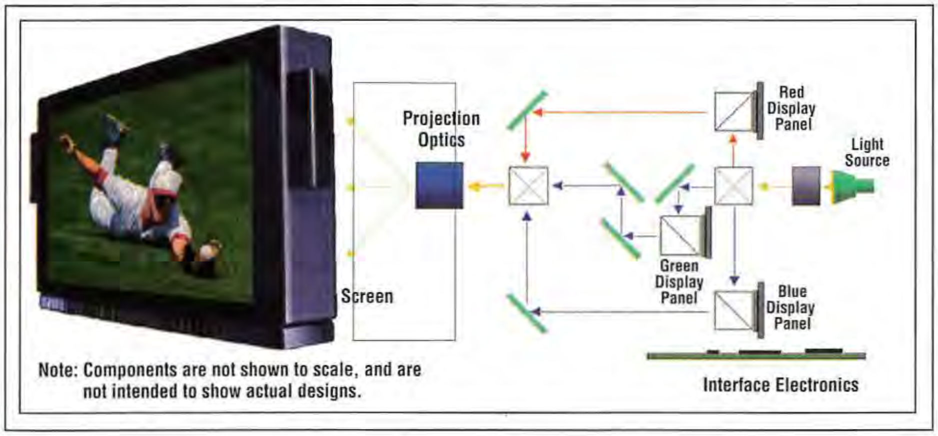

Fig. 4: Three-panel designs permit higher optical throughput than single-panel designs.

a microdisplay partnership

than number of pixels, is the primary driver of device cost, this permits a very cost-effective high-resolution projection solution.

At present, it is the limitations of projection optics - not of LCOS technology - that constrains the practical resolution of these devices, whose total optical throughput is in the range of 60–65%, making overall "optical engine" efficiencies of 5–10% readily achievable. This permits very competitive brightness levels at standard screen sizes, with relatively inexpensive light sources.

FLCs offer several unique advantages for projection use. First, the very high switching speed of FLC cells makes single-panel field-sequential-color projection displays possible, while still providing full 24-bit color at high frame rates (Fig. 3). The complexity and cost of such displays is much less than those using other microdisplay technologies. FLCs can, of course, still be used in three-panel designs for those applications requiring the optical-throughput advantages of a three-panel configuration (Fig. 4).

In addition, the small LC cell gaps and lower switching voltages possible with FLC materials provide other advantages. A thinner LC cell makes for reduced "crosstalk" between adjacent pixels while still permitting small interpixel gaps for a high fill factor and little or no diffusion or "fringing" of pixel edges, which can occur when light has to pass through a thicker LC layer. The lower operating voltage means that FLC displays can continue to be made using standard CMOS processes, following advances in semiconductor technology that will enable either reduced die sizes and costs or higher resolutions for a given die size. FLC materials also switch "in plane" with the thin FLC cells, thus enabling the use of faster lower-cost projection optics for improved optical efficiency.

Compared with current direct-view display technologies, projection units based on reflective microdisplays can provide several performance advantages. Because reflective displays do not rely on color subpixels, the appearance of color images is significantly better than with either CRTs or direct-view LCDs - and at a cost that can be very competitive with CRTs for all but the smallest screen sizes.

The Achilles heel of projection displays so far has been the light source, which has a relatively limited lifetime. However, there is still an advantage in this area over older technologies. Projection lamps are expected to be easily replaceable by the user, and replacement of a failed or aged lamp will restore "like-new" performance to the display. Contrast this with LCD monitors or CRT displays. Failed backlights are often difficult and costly to replace, and nothing can be done to correct a dim or failed CRT short of replacement of the entire tube/yoke assembly. In both cases, replacement of the entire product is usually a more cost-effective option.

Beyond Technology

Identifying and addressing unique microdisplay challenges are necessary steps that cannot be skipped over or lightly dismissed. Manufacturing logistics and market development are crucial to the evolution of microdisplay technology and the promise it represents. Over the last ten years, Displaytech has evolved from an R&D-oriented company to a product-oriented company. Following on this long and difficult transition, the company has invested in powerful strategic business relationships. In addition to the alliance formed with HP, Displaytech also has relationships with Samsung Electronics, Nissho Electronics, and most recently with Miyota, Japan's leading manufacturer of precision-processed electronic components. It is exciting for us at Displaytech to see real markets finally emerging for microdisplays. ■

Please send new product releases or news items to Information Display, c/o Palisades Institute for Research Services, Inc., 411 Lafayette Street, 2nd Floor, New York, NY 10003.

SID Conference Calendar

Next Show!

The 1999 International Display Research Conference (EuroDisplay '99)

The 19th edition of the International Display Research Conference will be held at the Maritim ProArte Hotel in Berlin, Germany, September 1–6, 1999. This year's conference is comprised of 49 papers from Asia, 46 from Europe, and 18 from the U.S. and Canada. The presentations reflect the current thrust of flat-panel research on organic LEDs, virtual displays, and light valves on Si for projection, printing replacing vacuum processes, and reflective displays with color or multiline addressing. A highlight promises to be the performance of the Berlin Philharmonic.

6 SEPTEMBER 99

19th International Display Research Conference (Euro Display '99)

BERLIN, GERMANY
SEPTEMBER 6–9, 1999

- An international conference on display research and development aspects of:
  - Display Fundamentals, Display Devices,
  - Hard Copy & Storage, Input Systems,
  - Integrated Devices and Applications,
  - Image and Signal Processing,
  - Color Perception, Human Factors

8 NOVEMBER 99

Fifth International Conference on the Science and Technology of Display Phosphors

SAN DIEGO, CALIFORNIA
NOVEMBER 8–10, 1999

- An international conference on the future prospects of phosphors for:
  - OLEDs – ELDs – FEDs
  - CRTs – Plasma Displays
  - PL Devices – LC Backlights

16 NOVEMBER 99

7th Color Imaging Conference: Color Science, Engineering, Systems & Applications

SCOTTSDALE, ARIZONA
NOVEMBER 16–19, 1999

- An international multidisciplinary forum for dialogue on:
  - Creation and capture of Color Images
  - Color Image reproduction and interchange
  - Co-sponsored with IS&T

14 MAY 00

SID '00

LONG BEACH, CALIFORNIA
MAY 14–19, 2000

- SID's MAJOR ANNUAL EVENT
- An International Symposium, Seminar, and Exhibition – Featuring:
  - Technical Sessions – Poster Session
  - Author Interviews – Evening Panels
  - Short Courses – Applications Seminars
  - Technical Seminars – Applications Sessions
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S-Vision Staked Its Claim, Then the Gold Mine Collapsed

S-Vision developed a technically successful digital LCOS display, found interested customers, bought a fab, and then found the company was built on a shaky foundation of "impatient capital" – justifiably impatient.

by Chris Chinnock, Al Davis, and Ken Werner

SILICON VALLEY entrepreneur Bruce McWilliams founded S-Vision in 1996. The company produced its first "Micro LCD" in March of 1997, and then focused its resources on developing new Micro LCDs with higher resolutions and complementary optical engines with known performances to expedite customers' time to market. In the second half of 1998, S-Vision established its own liquid-crystal-manufacturing facility in Twinsburg, Ohio.

But the company burned approximately $30 million dollars in 3 years and led investors to expect substantial revenue in 1999. Investors, perhaps justifiably, became impatient and pulled the plug.

"Our booth at SID '99 was already paid for," said Al Davis, sales VP for S-Vision and one of the authors of this article. "We wanted to show people what this technology could do. We got 300 leads at SID. If we had another 12 months and $15 million, we could have been in large-scale production and selling what we produced. But investors were given an unrealistic timeline. They became impatient."

The Plan

From the vantage point of 1996, McWilliams and his colleagues looked at the market projections for flat-panel displays – well over $20 billion by the year 2002, according to Stanford Resources – and saw an opportunity. On the surface, the technologies that seemed best positioned to capture large market share were AMLCDs, FEDs, PDPs, polysilicon AMLCDs, and CRTs. Each of these technologies had distinct technological advantages and disadvantages. The main disadvantages were (and are) yield, cost, high manufacturing investment, lack of easy scalability to larger display areas, and limited integration capability.

So there was a huge market opportunity for an alternative technology that could provide high-quality images, scalability in size and resolution, cost-effective manufacturing, and minimal overall system price. Such a technology was the combination of silicon and liquid-crystal technology known as the liquid-crystal-on-silicon (LCOS) microdisplay. S-Vision developed and began to manufacture LCOS microdisplays for front projectors, large-screen desktop monitors, and televisions.

The company assembled a staff of engineers, sales and marketing personnel, and administrators from companies that included Sun, IBM, Fujitsu, Thomson, RCA, Apple, HP, and In Focus Systems. Initial investment in the company came from Abrar Investments (Malaysia). Sand Hill Road and Silicon Valley venture capitalists Mayfield and Vertex made follow-on investments.

S-Vision's technology and intellectual property (IP) were focused on developing 100% digital reflective-LCOS-microdisplay imaging devices. The imaging devices used standard CMOS technologies capable of being manufactured in most fabs worldwide. The liquid-crystal materials were standard 45° twisted nematics. S-Vision designed the silicon in Santa Clara. The design was sent to a wafer fab that returned the process wafers to S-Vision, which finished the process by adding liquid crystal and performing final assembly in Twinsburg.

The S-Vision microdisplay imaging device had a greater than 93% aperture ratio, was inherently bright, produced a non-pixelated image, and was scalable to higher resolutions. Because the backplane of the imaging device

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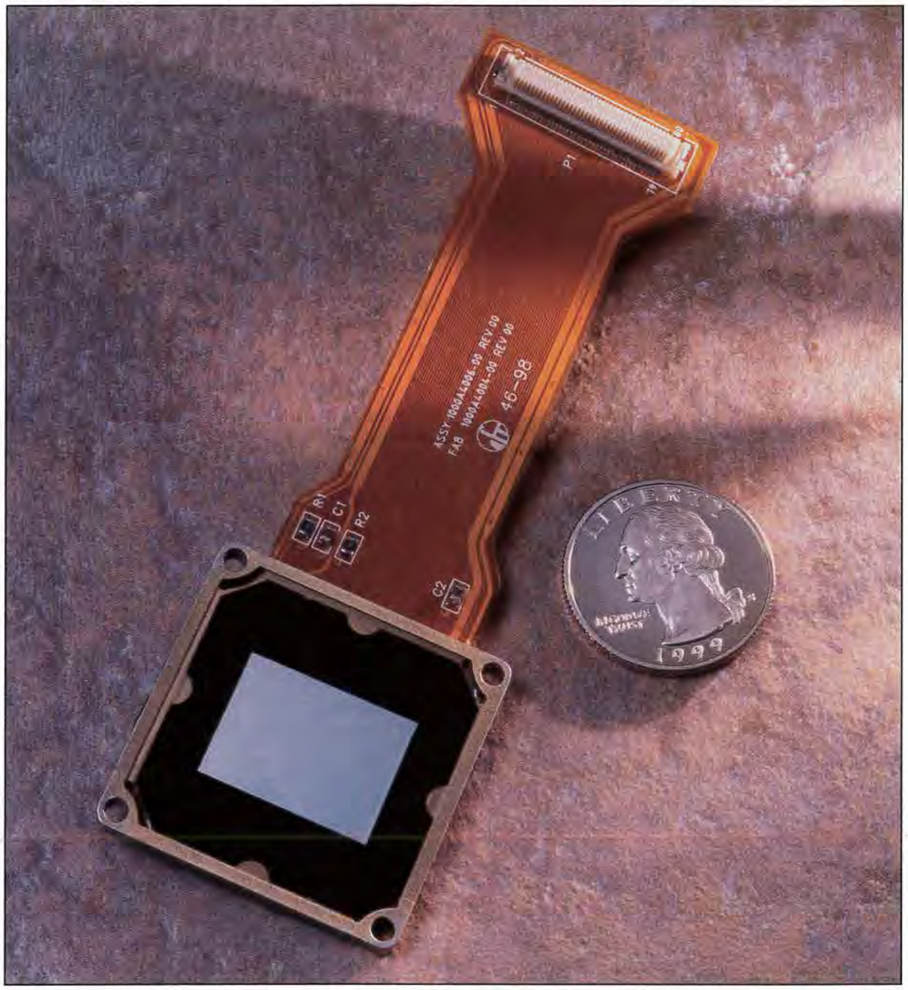


S-Vision

Fig. 1: S-Vision had produced an XGA LCOS imaging device, and was working on an SXGA device when the company ceased operations on May 13, 1999.

was basically a static RAM device, more functionality - such as frame buffers, line doubling, scaling, color tables, and convergence - could reside on the imaging device itself. In the first quarter of 1999, S-Vision was delivering XGA (1024 × 768) imaging devices (Fig. 1), and was finishing an SXGA design.

To reduce cost and time to market for potential customers, S-Vision planned to license reference designs for optical engines using its patent-pending off-axis design (Fig. 2). The internally developed reference designs were to be offered with demonstrated performance specifications.

Prior to the SID show in May 1999, S-Vision was fabricating its imaging devices on 8-in. wafers, each of which produced 55 candidate devices. Plans were to use improving design rules to decrease the overall physical size of the devices and increase the number of candidate devices per wafer. The company's intellectual property was concentrated on its digital backplane and LCD modulation, the off-axis optical system, and wafer-scale manufacturing processes.

S-Vision's business strategy was to offer Micro LCD imaging devices, supporting custom ASICs (when necessary), and licenses to optical-engine reference designs. The company planned to continue developing imaging devices to meet customer specifications, and to offer new and enhanced optical-engine reference designs to customers who felt that time to market was critical. Over time, S-Vision planned to integrate additional system functionality onto the silicon.

The Reality

S-Vision shocked attendees at the SID '99 show by quietly disclosing it would be liquidating assets and ceasing operations. Initially, the company maintained a stiff upper lip and declared that business continued as usual. Ironically, the company's booth at SID was packed with people interested in the rear-projection monitor the company was showing.

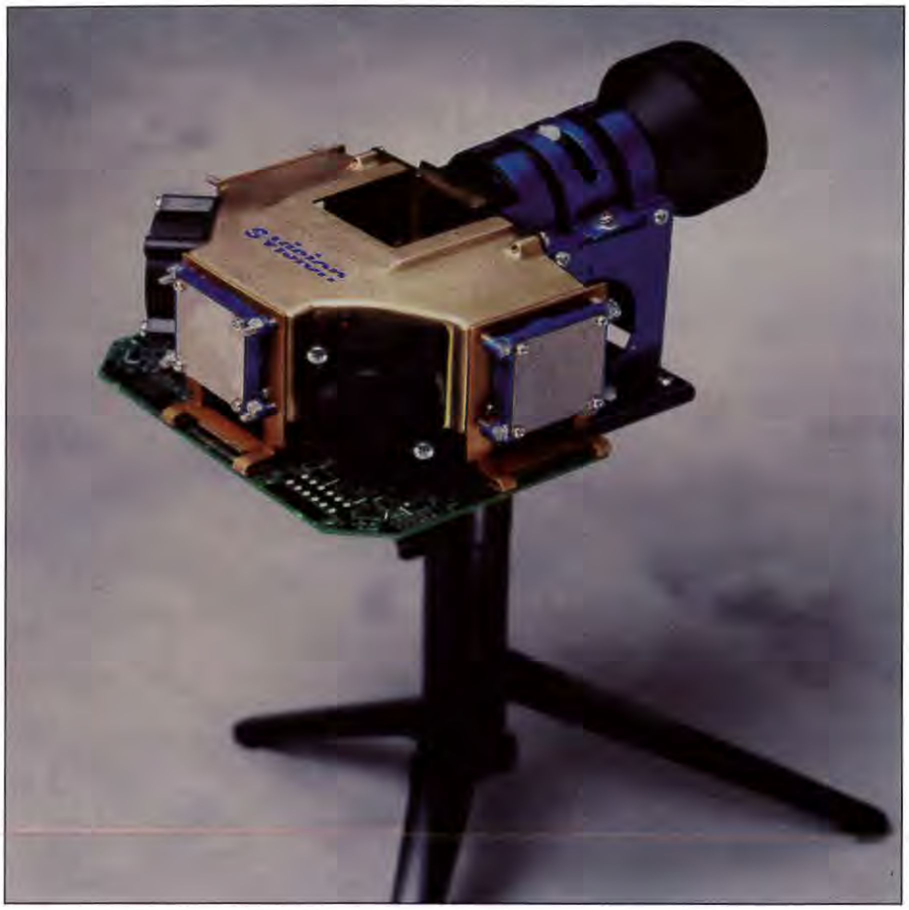
The company's failure underscores the fragile state of many microdisplay developers, who are heavily financed by venture capital and dependent upon rapid product-revenue streams. Apparently, a series of missteps and product-introduction delays forced S-Vision's Board of Directors to pull the plug.

For awhile, the picture looked bleak. But now there is late word that the Twinsburg facility will be sold to unnamed investors. What is not clear yet is whether S-Vision's microdisplay technology will survive.

What went wrong? About the time S-Vision produced its first LCOS display in 1997 it formed a projection-development partnership with Chisholm, but that had come apart by 1998 - primarily because of problems in manufacturing the LCOS displays. By the fall of 1998, S-Vision retreated from its plans to develop and sell an entire projection system. The company laid off personnel and refocused its efforts on manufacturing the LCOS displays and associated components for a light-valve engine.

Although the company had established an R&D and low-volume LCOS-processing facility in Twinsburg, they needed to establish a path to high-volume manufacturing. CMOS-backplane fabrication was already outsourced, so S-Vision decided to expand capacity in Ohio while finding a partner to invest in this facility to enable high-volume manufacturing. Ultimately, it is believed, the company's Board of Directors did not want to be in the manufacturing business at all.

Consequently, the company pursued a strategy of licensing their LCOS-manufacturing process to other LCD foundries. One company that S-Vision approached, Amkor Technologies (Chandler, Arizona), decided not to enter into an LCOS-manufacturing partnership with S-Vision for a number of reasons. Perhaps the most fundamental of these was



S-Vision

Fig. 2: The Nova rear-projection optical engine was a reference design that S-Vision planned to license to its microdisplay customers.

Amkor's concern about recouping their investment and turning a profit. Not only would they have to invest $5–10 million to modernize the S-Vision facility, but they would have to spend a year improving operations to bring yields up - probably to over 90%. Given the low selling price of the final LCOS displays - $200 to start and dropping to $50 - and the competitive display environment, that meant the sale of a lot of displays. It was a dicey business model.

Amkor was also concerned about the fact that the LCD-manufacturing infrastructure is not well established in the U.S. and that Ohio is well off the beaten path. Apparently, Amkor did consider establishing a fab in some vacant clean-room space in Arizona or even in their new state-of-the-art facility in Korea. But Texas Instruments is keeping that Amkor foundry very busy manufacturing DSPs, so resources that might have been devoted to the S-Vision project were already profitably utilized. All of these factors persuaded Amkor not to pursue a deal.

Making matters worse, cash flow was becoming a problem for S-Vision. The Mayfield Fund declined further investments, apparently feeling that the company had poor management and lack of market focus. The company's third round of funding, which was supposed to close last fall, didn't occur until this April. A series of bridge loans carried the company in the meantime.

But what may have been the last straw was either the delay or the cancellation of a major projection project. While company officials won't confirm it, the rumor is that Compaq was the customer developing a rear-projection computer monitor. Problems in finding an adequate screen solution is thought to have affected this product introduction, but other factors may be involved too, such as the lack of a high-volume LCOS fab. S-Vision was counting on revenue from this product in 1999, and now that won't happen.

Clearly, S-Vision was going to need more cash to survive and a new approach to solve their high-volume-manufacturing problem. The company turned to a customer, Vertex (Singapore Technologies), to help salvage the company. Vertex asked Klaus Von Wiemer, a well-respected architect of fabless manufacturing, to take a look at the situation. Apparently, he reported S-Vision's problems as fixable, but a challenge. The conservative Vertex, already doubtful, was not pleased by this news. They declined to help the company. As a result, on May 13, S-Vision's Board of Directors voted to cease operations.

The company's collapse was not inevitable. S-Vision had developed solid LCOS technology. Samsung, another reported customer, was showing signs of serious interest in a rear-projection computer monitor, supposedly even moving people to California. At the INFOCOMM exhibition held in Orlando in June, several customers were expected to debut products based upon S-Vision devices and the company's Nova projection engine, but none were in evidence on the show floor.

What will unfold next is still unclear. S-Vision's IP is being licensed, says Davis, and the LCOS displays will be produced, although not under S-Vision's brand. But the company's closure or facility resale is still likely to put many of its customers in a hard spot. They will not be able to simply substitute another manufacturer's LCOS display in a projection product designed for the S-Vision device. While this could motivate a customer to come to the rescue, most appear to have already declined the opportunity. ■

calendar

8 **99**

NOVEMBER

Fifth International Conference on the Science and Technology of Display Phosphors

SAN DIEGO, CALIFORNIA
NOVEMBER 8–10, 1999

- An international conference on the future prospects of phosphors for:
  - OLEDs – ELDs – FEDs
  - CRTs – Plasma Displays
  - PL Devices – LC Backlights

16 **99**

NOVEMBER

7th Color Imaging Conference: Color Science, Engineering, Systems & Applications

SCOTTSDALE, ARIZONA
NOVEMBER 16–19, 1999

- An international multidisciplinary forum for dialogue on:
  - Creation and capture of Color Images
  - Color Image reproduction and interchange
  - Co-sponsored with IS&T

SID '00

Long Beach, California

Long Beach Convention Center

May 14–19, 2000

The 7th International Conference on Ferroelectric Liquid Crystals (FLC '99). Contact: Prof. Wolfgang Haase, Condensed Matter Research Group, Institute of Physical Chemistry, Darmstadt University of Technology, Petersenstraβe 20, D-64287 Darmstadt, Germany; +49-61-51-16-33-98, fax -49-24, e-mail: flc99@tu-darmstadt.de, http://flc99.tu.darmstadt.de.
Aug. 29-Sept. 3, 1999 Darmstadt, Germany

The 19th International Display Research Conference (EuroDisplay '99). Sponsored by SID and in cooperation with ITG. Contact: Dipl.-Ing. Rupert Rompel, VDE Verband Deutscher Elektrotechniker e.V., Stresemannallee 15, D-60596 Frankfurt am Main; +49-69-6308-381, fax +49-69-9631-5213, e-mail: 100145-67@compuserve.com.
Sept. 6-9, 1999 Berlin, Germany

The 6th Annual Flat Panel Strategic and Technical Symposium, *"Vehicular Applications of Displays and Microsensors."* Sponsored by The University of Michigan Center for Integrated Microsystems and the Metropolitan Detroit Chapter of SID. Contact: R. Donofrio, Display Device Consultants, 6170 Plymouth Rd., Ann Arbor, MI 48105; 734/665-4266, fax -4211, e-mail: rldonofrio@aol. com.
Sept. 22–23, 1999 Ypsilanti, MI

The Fifth International Conference on the Science and Technology of Display Phosphors. Sponsored by SID, PTCOE, and DARPA. Contact: Mark Goldfarb, Palisades Institute for Research Services, Inc., 411 Lafayette St., New York, NY 10003; 212/460-8090 x203, fax -5460, e-mail: mgoldfar@newyork.palisades.org.
Nov. 8–10, 1999 San Diego, CA

Electronic Information Displays (EID '99). Sponsored by the SID UK/Ireland Chapter. Contact: Trident Exhibitions, Jon Jones, West Devon Business Park, Brook Lane, Tavjstock, Devon, PL19 9DP, U.K.; +44-1822-614-671, fax -818.
Nov. 16–18, 1999 Surrey, U.K.

The Seventh International Color Imaging Conference. Sponsored by IS&T and SID. Contact: IS&T, 7003 Kilworth Lane, Springfield, VA 22151; 703/642-9090, fax -9094, e-mail: info@imaging.org.
Nov. 16–19, 1999 Scottsdale, AZ

Flat Information Displays Conference

In Stanford Resources' annual snapshot of the display industry, good and bad news abounded – but advances in the face of uncertainty appeared to be the order of the day.

by Stephen P. Atwood

STANFORD RESOURCES hosted the 15th annual Flat Information Displays Conference on the lovely but rainy Monterey Peninsula December 2–3, 1998. Despite the wet weather, Stanford Resources' President and CEO Joseph A. Castellano greeted conference attendees with a warm welcome. Over the course of the 2-day conference, three major stories rose to the surface.

Coming into this year's conference, we saw the average selling prices of many LCD panels sharply reduced by a combination of cutthroat competition and significantly increased manufacturing capacity in the Pacific Rim. Companies that invested heavily in 1996 and 1997 were willing to reduce prices, sometimes below cost, to gain market share and generate volume for their fabrication lines. The message to conference attendees was that 1999 would see a backlash due to the fall of manufacturing-capacity investment to almost zero and the consequent attempt by suppliers to use allocation techniques to reverse the price erosion.

We also saw the war between competing interface standards for LCD monitors heat up as monitor companies began to align themselves behind one approach or another. While this topic has been covered extensively elsewhere, it is worth pointing out that two prominent digital standards emerged - OpenLDI, which uses an extension of LVDS, and various proposals using PanelLink - and NEC made a strong argument not to pursue digital at all.

The third big story was the announcement by at least two companies of significant new investments to build field-emission displays (FEDs) here in the United States. These three themes - along with highlights from other presentations - made for a full and thought-provoking program.

Generation Next

Professor Jeffrey Hart of Indiana University gave a summary of his team's study of the global flat-panel industry. One critical issue when building new plants is the choice of substrate size. For a standard size, tools will be readily available, but there is a risk of falling behind competitively as demand shifts to larger panel sizes. Historically, there has typically been one innovator who needed to push the substrate size upward and therefore assumed the challenge of testing the new standard and bringing the toolmakers on board.

At the moment, it looks like Hitachi could be the innovator for Gen 4. They have chosen a substrate size of 650 × 830 mm and declared that they will build their own tools if the toolmakers are not able to address this standard. Hitachi's production will yield nine 12.1-in.

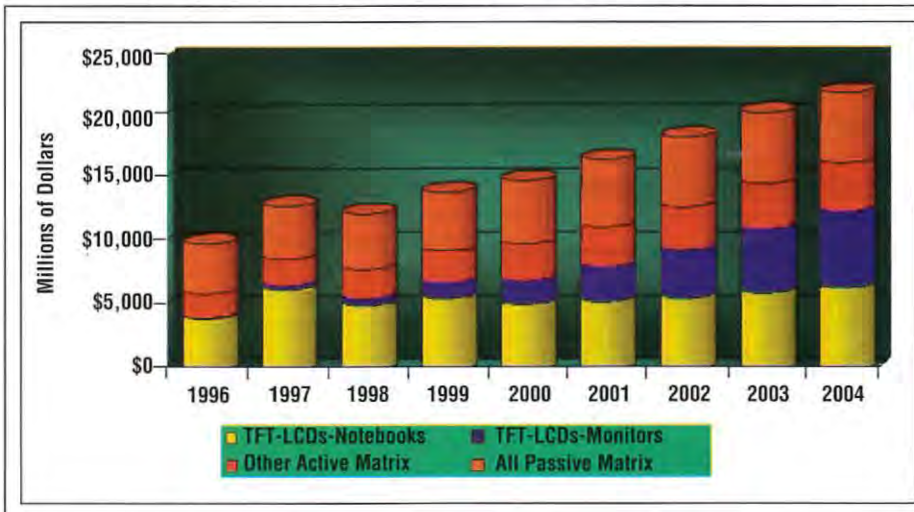


Fig. 1: The total LCD market is projected to increase substantially by 2004. (Courtesy of Stanford Resources.)

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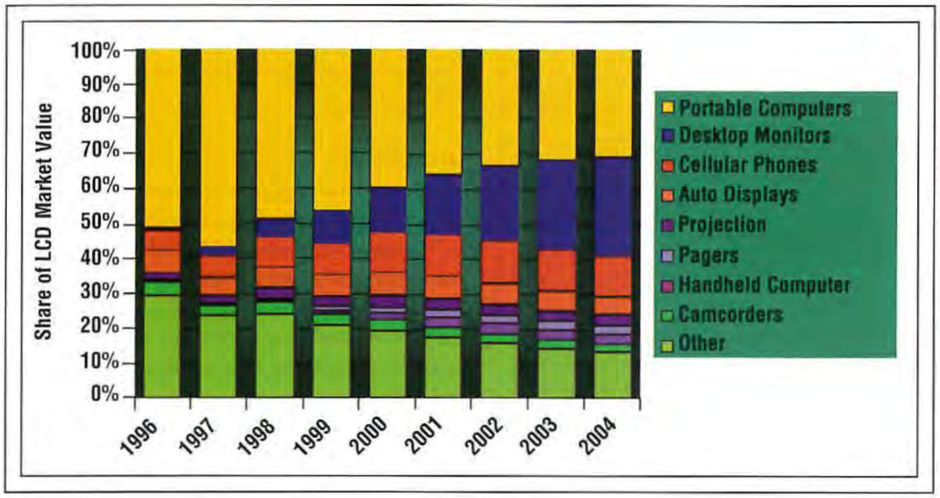

Fig. 2: Desktop monitors will account for an increasing share of the LCD market by 2004. (Courtesy of Stanford Resources.)

panels, six 13.3-in. panels, or four 17.x-in. panels per substrate. Their choice is already controversial because Sharp and Samsung have made commitments to produce 18.x-in. products instead of 17.x-in. Other proposals for Gen 4 have been made by SEMI Japan, DTI, Applied Komatsu Technology, and Ohmi Laboratory for sizes ranging from 800 × 950 mm up to 960 × 1100 mm. This diversity is one of many problems holding back Gen 4 investment.

Professor Hart's conclusion was that Gen 4 investment will come, but, given the projected shakeout in pricing and supply for 1999, new investments will come slowly and at a more considered pace than in earlier generations.

Peering into the Liquid-Crystal Ball

One of the most eagerly anticipated sessions at this conference each year is the annual snapshot of the LCD-panel business. Paul Semenza, Director of Market Analysis for Stanford Resources, presented an analysis of market numbers. The first headline was no surprise: The market for LCDs in both units and dollars continues to grow at a very healthy rate.

In 1998, more than 1.6 billion units shipped, worth about $15 billion. Since this number includes all types of LCDs, it is more useful to look at market value for specific LCD technologies. For example, panels for notebook applications are responsible for more than half the total market value, at more than $7.5 billion. This value represents a decline from $8.5 billion in 1997, caused by the tremendous price erosion in LCD panels in 1998. Looking forward, Stanford Resources predicts that by 2004 the active-matrix-panel market will exceed $15 billion (Fig. 1).

The expanding laptop business and the beginnings of the desktop-monitor business are making headlines as the leading product applications for LCDs (Fig. 2).

Unfortunately, while the sharp price declines in 1998 have been good for the growth of unit sales and have accelerated penetration into markets such as desktop monitors, it has been an unusually challenging year for panel manufacturers. From Q2 '97 to Q2 '98, the average price for a 12.1-in. notebook TFT fell from $650 to around $225, a factor of nearly 3. Larger sizes saw similar declines and TFT desktop-monitor panels followed suit.

In many cases the market is beginning to show the properties of a commodity market, and major OEMs are exerting significant pressure to keep prices low and supplies high. This led to speculation about whether the LCD business was capable of being profitable in the future. Several companies, including Sharp, implied that they lost "significant" amounts of money in 1998 on the LCD business.

There were assertions that the vertically integrated players like Toshiba lost less money because they had the margins of notebooks or monitors to support them. In spite of this, several new producers are expected to join the fray, including a half-dozen in Taiwan and one new entrant from both Korea (Daewoo) and mainland China (Jilin, with technology transfer from DTI).

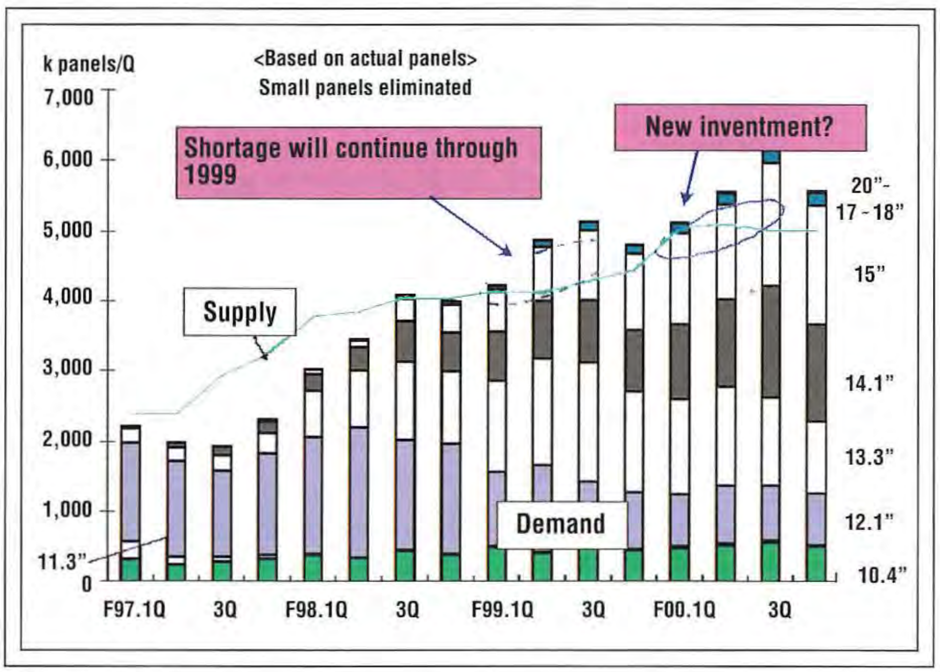

Fig. 3: NEC projects that TFT-LCD demand will exceed supply at least through 1999. (Courtesy of NEC Corp.)

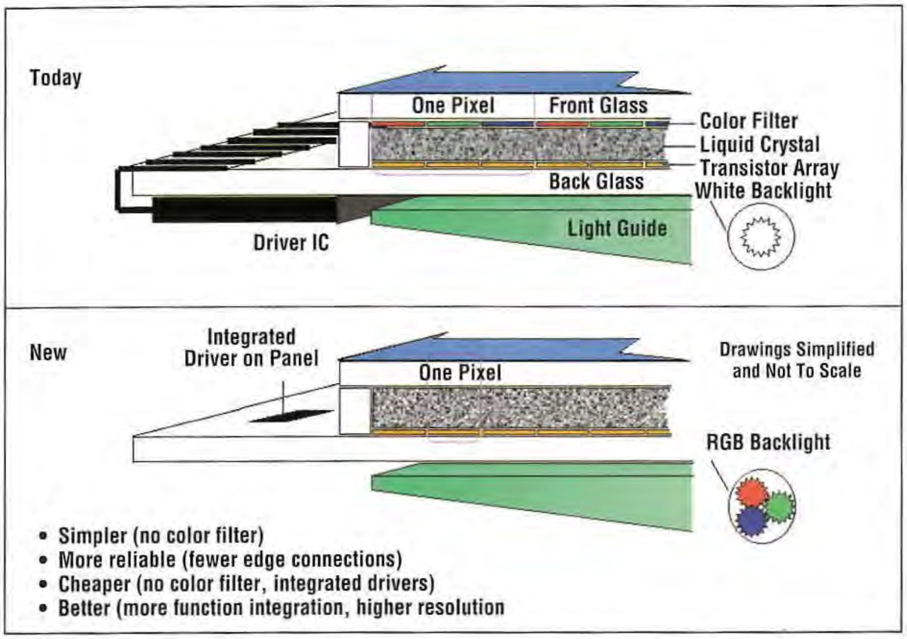

Fig. 4: *Symmorphix's design of a low-temperature-polysilicon structure for TFT-LCDs puts the color filters on the backlight. (Courtesy of Symmorphix.)*

Still, there was precious little optimism presented for investments in additional manufacturing capacity. The clear message was that investment in additional capacity by existing suppliers would be slow and would probably not result in any additional price-reduction opportunities for at least 18 more months. As a result, 1999 will see greatly tightened supplies, quarterly allocations, and some price increases due to market demand and currency fluctuations.

From a format perspective, the dominant size in 1998 was 12.x in., followed by 13.x in. The expectation is that demand for 12.x in. will fall and the demand for 13.x and 14.x in. will rise significantly in 1999. NEC's Omid Milani projected that demand for sizes in the 13–15-in. range will quickly become at least half the total market, which is somewhere between 4.5 and 6 million panels, depending on whose numbers are used (Fig. 3).

Mechanical-Interface Standards

The presentation given by Paul Salisbury of Dell Computer Corp. issued a challenge to LCD manufacturers to get together and standardize a number of common electrical and mechanical elements on notebook panels to make the OEM integrator's life much easier. Salisbury pointed out that as of his last count, there were 109 different models of 12.1-in. panels. One supplier offers more than 30 models of 13.3-in. panels. Within a given panel size, such as 12.1 in., there are variations in overall height and width, active-area centerlines, backlight connectors and wire lengths, mounting holes, I/O connections, and quality levels. Salisbury presented a strawman outline for what a standard might look like. A brief survey after the meeting found some degree of support for his efforts among quite a few manufacturers and OEMs.

Enabling LTPS

At last year's SID symposium in Anaheim, several manufacturing-equipment suppliers were talking about their efforts to support the development of low-temperature-polysilicon (LTPS) LCDs. Bill Lee, V.P. of Marketing for Symmorphix, presented the other side of the struggle – that of a technology developer trying to enable the LTPS market. Their approach to an LTPS architecture moves the color filters out of the liquid-crystal stack and places them in the backlight structure, along with semiconductor changes (Fig. 4). This approach reduces the number of production steps and costs for the panels, which in turn reduces the losses from defective panels. While LTPS promises improvements in performance as well as cost, many hurdles must still be overcome.

Onto the Desktop

Rhoda Alexander of Stanford Resources presented an overview of the significant fall in LCD-monitor prices during 1998 as a result of panel price reductions, overproduction, and channel issues. She went on to project much more moderate price reductions in the future, as well as only moderate unit volume growth in 1999.

A major challenge for LCD monitors is that while their prices have fallen dramatically in the past year, CRT-monitor prices also fell. Furthermore, CRTs don't have the digital-*versus*-analog interface debate to resolve, enjoying a well-established and dominant standard already on desktop-computer systems.

Tom LaRocca of Compaq shared some of his company's perspectives on flat-panel displays in Compaq's market space. Compaq currently sells between 8 and 9 million monitors per year. For 1999, the company projects that just 3% – roughly 250,000 units – will be LCD monitors. Compaq believes that in order for LCD monitors to be accepted by customers, there must be improvements in set-up, wider viewing angles, better color depth, narrower bezels, longer-life backlights, network management features, screen rotation (landscape to portrait), and touch-screen support.

On the interface side, Compaq supports the VESA Digital Flat Panel (DFP) standard and plans to produce dual-ported units – analog and digital – in 1999. LaRocca also downplayed the importance of settling this debate immediately because Compaq sells mostly full systems.

Growing Support for FEDs

Field-emission displays are still in their early stages of development, but several companies have made significant investments in the technology. PixTech, Motorola, and Candescent expect to have manufacturing capacity running in the next year or so. Candescent has invested heavily in a new manufacturing facility in San Jose, and Motorola has been building new facilities as well. Look for small-format color and monochrome FEDs to become integrated into instrumentation and related applications in the near future. Larger sizes remain much further away.

Dieter Mezger of PixTech discussed his company's efforts in the FED marketplace. PixTech is selling small-format (5.2-in.) low-voltage monochrome displays for use in medical instrumentation today, with color production in similar sizes expected by late 1999. The company's plans include 7-in. color displays that use high-voltage technology, with sampling to begin in late 1999 and manufacturing 18 months after that. A 15-in.-prototype program is under way, with production forecast within 2 years.

Stewart Hough, Marketing Manager at Candescent Technologies, discussed his company's efforts to bring "ThinCRTs" to production. (Candescent uses the name "ThinCRT" to describe its version of FED technology.) Candescent's business model is focused on a combination of strategic partnerships and large-scale private financing of over $240 million. After completing manufacturing trials on a 5.3-in. QVGA product this year, the company started construction on a new manufacturing facility to handle substrates up to 590 × 670 mm.

The facility will produce more than 500,000 12.1-in.-equivalent displays per year when it is finished. Candescent claims this will be the most advanced FPD facility in the Western Hemisphere. Meanwhile, the company has entered into a 2-year partnership with Sony Corp. with a 50%-shared $100 million investment to begin developing technology for 14-in.-and-larger displays.

The View from a Distance

This year's conference represented an extremely diverse cross section of flat-panel topics and issues. While any summarization would be overly simplistic, it is noteworthy that the markets being developed probably exceed anyone's visions of just a few years ago; yet, the perennial predictions of the demise of CRTs, of paperless offices, and of full-matrix displays on every appliance are still over the horizon.

The flat-panel market is beset with challenges and opportunities, facing stiff competition from within and without, and continuously coping with shifting financial climates in different parts of the world. The industry is also grasping to identify the "killer application" that rockets one of the new technologies to pervasive status - a larger version of the success seen by LCDs in notebook computers. The clear message from this conference is that flat-panel displays are growing in performance, acceptance, and significance. The only questions remaining are how big? how far? and how fast? ■

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Michigan Strategic and Technical Symposium

A strategic vision and a slant toward automotive display technology has created a regional conference with more than regional appeal.

by Samuel Musa and Robert Donofrio

THE Fifth Annual Strategic and Technical Symposium, sponsored by the Metropolitan Detroit Chapter of the Society for Information Display (SID) and the University of Michigan's Center for Display Technology and Manufacturing, was held September 9–10, 1998. The two-day symposium was attended by over 200 managers, engineers, scientists, marketing people, faculty, and students in the field of displays. Unfortunately, the strike by Northwest Airlines caused several last-minute cancellations by attendees and speakers.

A number of exhibitors showed their new equipment, and the exhibit tables were also used by some speakers to physically show the technology discussed in their oral presentations (Fig. 1). This was a different procedure from that seen at SID's International Symposium exhibits, and it produced lively discussions. Some of the exhibits were set up directly outside the doors of the lecture room and were well attended during breaks.

The keynote speaker was Gary Jones, President of FED Corp. Jones discussed strategies that would allow U.S. companies to succeed in the display business, ranging from the scale-up of new technology to partnerships and licensing opportunities.

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He was followed by Bruce Gnade, Program Manager at the U.S. Defense Advanced Research Projects Agency (DARPA), who presented an overview of the DoD's High Definition Systems (HDS) Program. He emphasized new directions within the program that are addressing the need for flexible rugged displays, pushing maturing technology to the demonstration stage, and moving HDS-developed technology into products.

Gnade was then followed by Darrell Hopper of the U.S. Air Force, whose presentation focused on the DoD Display Strategy, and Richard Van Atta of the Institute for Defense Analyses (IDA), who presented some observations on the recent DoD Insertion Study dealing with commonality, open systems, obsolescence, and COTS.

The World Outside the Hall

But as the meeting proceeded successfully (in spite of Northwest Airlines), a number of events were occurring independently that would have a large impact on the Midwest display community. Just before the meeting, it was learned that the display maker OIS was closing its doors, thus ending the grand experiment with AMLCD manufacturing in Michigan.

The talks by Bruce Gnade, Darrell Hopper, and Richard Van Atta were peppered by questions along the lines of "What's going to happen now?" What would be done with those aircraft sitting on the tarmac with instrument panels waiting for the OIS AMLCDs that would now not be made? Such questions resulted in a lively debate during the panel discussion in the strategic and business issues session.

Sometime after the meeting, we learned that some of the former OIS business was picked up by dpiX and Planar, and the rest by established defense contractors integrating glass from Asian suppliers. A small number of people were kept at OIS to complete the last in-process orders.

The audience remained enthusiastic about the topics covered in the symposium, while conversations continued about the OIS problem during breaks and lunches.

The Technical Program

Among the 30 papers presented at the symposium was a vehicular-display paper given by Michael Heimrath of BMW. His statement that BMW would use 51,000 LCDs with full graphics capability in their cars in 1998 made the audience aware of how quickly the display situation is evolving at one of Europe's premium auto makers. His instructive and enjoyable paper won the Best Paper Award.

Pete Matheson of Intel discussed a new trend in communications in the automobile. Items such as cellular phones, GPS receivers, and accelerometers can be integrated into a smart navigation system, which can be used to automatically request emergency road service in the event of an accident. Route-planning systems that respond in real time can inform the driver of roads that are being closed as a result of accident or road repairs. Plans are afoot to integrate PCs into the vehicle and have them run on the car's information bus.

Reconfigurable displays were discussed in a talk by Mike Schioak of the Vehicle Monitor Corp. (VMC). VMC used a vehicular data bus and its "Smart Display" to integrate all

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Pamela Bogdanski, CIMS

***Fig. 1:** In the exhibits, United Technologies Automotive demonstrated its concept of a modern instrument cluster.*

gauge, message, fault-detection, and diagnostic functions on a single GUI. Another paper in the same vein was presented by Phil Zuk of Vansco Electronics, in which he described FPD applications in agricultural equipment. ELs, AMLCDs, and LCDs are being used in tractors, combines, and off-the-road construction equipment. Vansco is now incorporating Planar EL displays in new designs because of better performance in withstanding vibration, temperature, and heat.

One of the interesting areas in which GPS and displays are involved is "precision farming" - where a field is mapped by taking soil samples which are analyzed to see what nutrients are lacking. The information is made available to the operator through a PC, which allows chemicals to be dispensed in a controlled manner.

Measurement and fabrication issues concerning backlights were addressed by Adi Abileah and Bob Donofrio, and Mark Horner of Sharp discussed a self-heating backlight giving a rapid on-time. Tina Brunetti Sayer of the Environmental Research Institute of Michigan (ERIM) described her human-factors study, incorporating an FPD in a USMC transport truck, that concluded that the display should be placed within 15° of the line of sight and that a visor should be placed around the display to reduce glare.

The Symposium received sponsored support from Delphi Delco Electronics Systems, The Dow Chemical Company, OIS Optical Imaging Systems, the United States Display Consortium, and United Technologies Automotive. In addition, Integral Vision (manufacturers of automatic inspection equipment) hosted a widely appreciated reception in the evening that provided an opportunity for further discussion of the presentations at the symposium.

The Strategic and Technical Symposium serves a unique role in the display arena in that it focuses on the business and strategic issues, as well as the vehicular applications of display technology. The conference planners are looking forward to another successful symposium this year to be held September 22–23, 1999, in Ypsilanti, Michigan. The main theme will be vehicular applications of displays and microsensors. ■

continued from page 4

After encountering this phenomenon a number of times, I have come to the conclusion that we have a built-in "goodness meter" that calibrates our visual senses against our environment and against the best displays that we commonly see in products. Of course, until recently these were always CRTs. We use this goodness meter whenever we look at a new technology. Our goodness meter has a response function not unlike that of an electroluminescent material, *i.e.*, there is not much response until we hit a threshold value and then we "light up." Our perception of display goodness is threshold dependent. The threshold is set by what we have decided is good enough. When a new technology crosses that threshold, we embrace it. Like the arrival of new Beaujolais wines in France every fall, "Le Beaujolais Nouveau est arrivé," we announce the arrival of a new display technology as now being product-ready and "Good enough!"

Because our perceptions are so threshold dependent, being able to quantify this crossover point becomes highly important for technology-development and product-marketing purposes. It's also important for us to know where this threshold is if we are in businesses that support certain aspects of major new technologies.

One of the most significant technology battles currently being waged is between traditional film-based photography and digital imaging. We have in previous columns addressed some of the broader future impacts of this technology shift. As we have discussed, many forces are driving the growth of digital imaging. One of the most important – maybe even the most important – is the challenge for digital imaging to affordably meet or exceed the resolution of good-quality 35mm-film photographs, slides, and movies. In other words, where is the crossover point for a digital technology to produce images as good as 35mm-film still photography and movies in theaters? We know that the current crop of less-than-one-megapixel digital cameras isn't quite there. But if not, then do we know where "there" is?

The resolution capability of the best color 35mm films is in the range of 3000–4000 line-pairs, using the criteria of a barely distinguishable line and space (contrast ratio of less than 1.6:1). To accurately render that resolution with a digital imager could require as many as 10 megapixels, which is about an order of magnitude beyond the capability of the current crop of consumer digital cameras.

Film-based photography aficionados often quote these resolution figures to support the position that digital photography still has a long way to go. However, the capability of the film is only one factor in the quality of the final photograph, slide, or movie image. The final image is not only limited by the film, but also the resolving power of the lenses, the vibration of the camera during the exposure, the precision of the focus setting, and, finally, the capabilities of the printing system, or the projection system for slide images. Using the best 35mm camera lenses, under the best focusing conditions, the resolution capability of 35mm color photographs, slides, or movie images seldom surpasses a resolution of 1000 × 1500 line-pairs, well below the capabilities of the film itself. And if we succumb to the lure of modern zoom lenses with autofocus capability and combine these with higher-speed films, we will be lucky to achieve resolutions of 800 × 1200. For example, a typical slide that we see projected at a technical conference will have a resolution of about 800 resolvable line-pairs, but can even dip below 700 line-pairs if a low-quality projection lens is used.

Taking all this into account, we are led to the conclusion that the threshold of goodness for digital photography to be comparable to 35mm photographs is not 10 megapixels but closer to 2 megapixels. For 2 1/4 format photography, the threshold then becomes 5 megapixels, and for large-format 4 × 5-in. sheet film, the comparison threshold is around 20 megapixels. Ten- to twenty-megapixel photos are what we see when we look at the ultra-crisp b&w images created by Ansel Adams and other large-format landscape photographers.

This year and next, we will begin to see 2-megapixel digital cameras at prices that more of us are willing to pay. Top-of-the-line 35mm-film-based cameras are in the $1000–2000 range already. Two-megapixel digital cameras will be available in this price range by about the time you read this column. Digital photography is almost here. It will be crossing the "threshold of goodness" this year. Together with the rapidly improving capabilities of color printers, we can expect the major impact of digital photography to occur over the next 2–5 years. The age of digital imaging "est arrivé."

The implications are equally significant for the movie industry. Since most movie-theater audiences (except IMAX) have learned to like resolutions of no better than 1000 × 2000, we are ideally positioned to replace movie film with digital image distribution using the already agreed upon 1080 × 1920 progressive HDTV format. The technology to do this will be refined over the next 2–3 years, and then the only limitation will be the rate at which the movie theaters will find it economically advantageous to make the changeover. This electronic imaging format will have the capability of displaying images significantly *better* than the current film-based ones. Therefore, if the movie makers choose to also use high-

resolution digital image capture instead of film, the movie-theater experience will be able to move to a new level of "good enough."

For the die-hard 35mm-film-photography buffs who are still in denial but would like an opportunity to discuss this topic further, you can reach me by e-mail at silzars@ibm.net, by phone at 425/557-8850, by fax at 425/557-8983, and by the regular printed mail at 22513 S.E. 47th Place, Issaquah, WA 98029. I only ask that you not get too upset with me for the information I have provided in this column. After all, it's not my fault that technology to which you have contributed has made your film go bad.

As an added, extra bonus, feature for this month only, I am including a resolution photograph with this column, taken under close-to-ideal conditions, so that you can get at least a rough idea of the resolution capability of a typical snapshot-sized photograph. If you would like an actual copy of a slide or a 4 × 6-in. print (suitable for projection or framing) please let me know. After all the requests are collected, I will mail you your very own 35mm-photograph resolution verifier. ■

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editorial

continued from page 2

CPT's partner is Mitsubishi, which supplied the display and manufacturing technology. One hundred CPT people trained at Mitsubishi for between 4 and 9 months each to transfer the technology. Mitsubishi has the right to purchase 30% of CPT's output, and there are already orders from Taiwan manufacturers of notebook computers and desktop monitors, including CPT's parent company, Tatung.

Liang commented that six Taiwan companies - Prime View, Unipac, Chi Mei, Acer Display, and HannStar, in addition to CPT - are now manufacturing amorphous TFT-LCDs or completing their plants. As a result, there are not enough engineers available to work on next-generation technologies such as low-temperature polysilicon.

CRTs

By the time you read this, CPT will be making TFT-LCDs, but the company already makes CRTs - lots of them, at low cost - in two plants in Taiwan, two in Malaysia, one in mainland China, and one in Scotland. (CPT made about 15 million monitor tubes in 1998, about 19% of the world's supply.) I saw 15-in. CDTs being made in the automated Taoyuan plant, which also makes 14- and 17-in. tubes.

CPT was founded in 1970 and began making monochrome picture tubes based on RCA technology. Over the years the company added display tubes, and incorporated more and more of its own technology. Monochrome CRT and electron-gun production were moved to the Fuzhou plant in mainland China in 1995. The company began making color picture tubes using Toshiba technology in 1980, and added color display tubes in 1985.

CPT's continued success in the highly competitive large-volume tube business - prices dropped by 50% last year - rests on two factors, said Chen. First is CPT's 160-person equipment group, which designs and makes all of CPT's manufacturing equipment and works closely with product designers. As a result, the large automated plant I was touring was built from start to finish in only 9 months (working 24 hours a day) at much lower cost than would have been possible buying equipment from the outside.

The second reason was CPT's declaration of independence from Toshiba. The critical component CPT previously obtained from

Toshiba was the electron gun, and Toshiba controlled both price and quantity, said Chen. CPT received only second-tier guns, which made it impossible for the company to compete with high-resolution tubes. Chen himself designed new electron guns for the tubes, which are made at CPT. In fact, all CPT tubes now have a Chen-designed gun.

Given CPT's CRT experience of starting with borrowed technology and becoming increasingly competitive by incorporating home-grown technology and combining it with in-house design and construction of manufacturing equipment, it would be surprising if CPT executives were not already thinking of pursuing the same strategy with TFT-LCDs.

And New Ventures ...

CPT has always made components - CRTs and, now, LCDs - for others to integrate into end-user products. So I was surprised to find that the company has started making its own LCD front projectors based on Sony 1.3-in. panels. Sony panels are being used, said Cheng-Fung Lin, Director of the Optoelectronics Product Design Department, because the only other source, Epson, would not sell to CPT.

The current CPT product is an SVGA projector that produces 450 ANSI lumens from a 270-W metal-halide lamp. The projector showed nice video and includes a resizing function. Lin sees a consumer-TV application for front projectors when prices come down. (Having some competition among panel suppliers would help.)

An XGA projector now under development will use Sony 1.3-in. panels and produce 700 ANSI lumens from a 150-W Matsushita UHE lamp. CPT will shift to Sony 0.9-in. panels when they become available. The current price of the SVGA model is about $4000; the XGA model will be introduced at around $7000.

R&D Director Liang said that CPT has already made a prototype 25-in. plasma-display panel, and will have an experimental plant completed in October. Subject to corporate approval, the company plans to have a PDP pilot plant in operation in two years.

In the company's Yangmei location, CPT has an R&D plant for new CRTs from 14 to 40 in. on the diagonal.

Generous Hosts

The openness of my hosts at CPT was impressive. In the U.S., editors often have to sort through presentations of "vaporware" - and even "vapor companies" - presented by teams of skilled "spinmeisters." At CPT, there was not a PR person in sight, and both senior executives and middle managers worked hard to answer fully every question that was asked. CPT is no longer only a CRT company, and it wants the world to know it.

- Ken Werner

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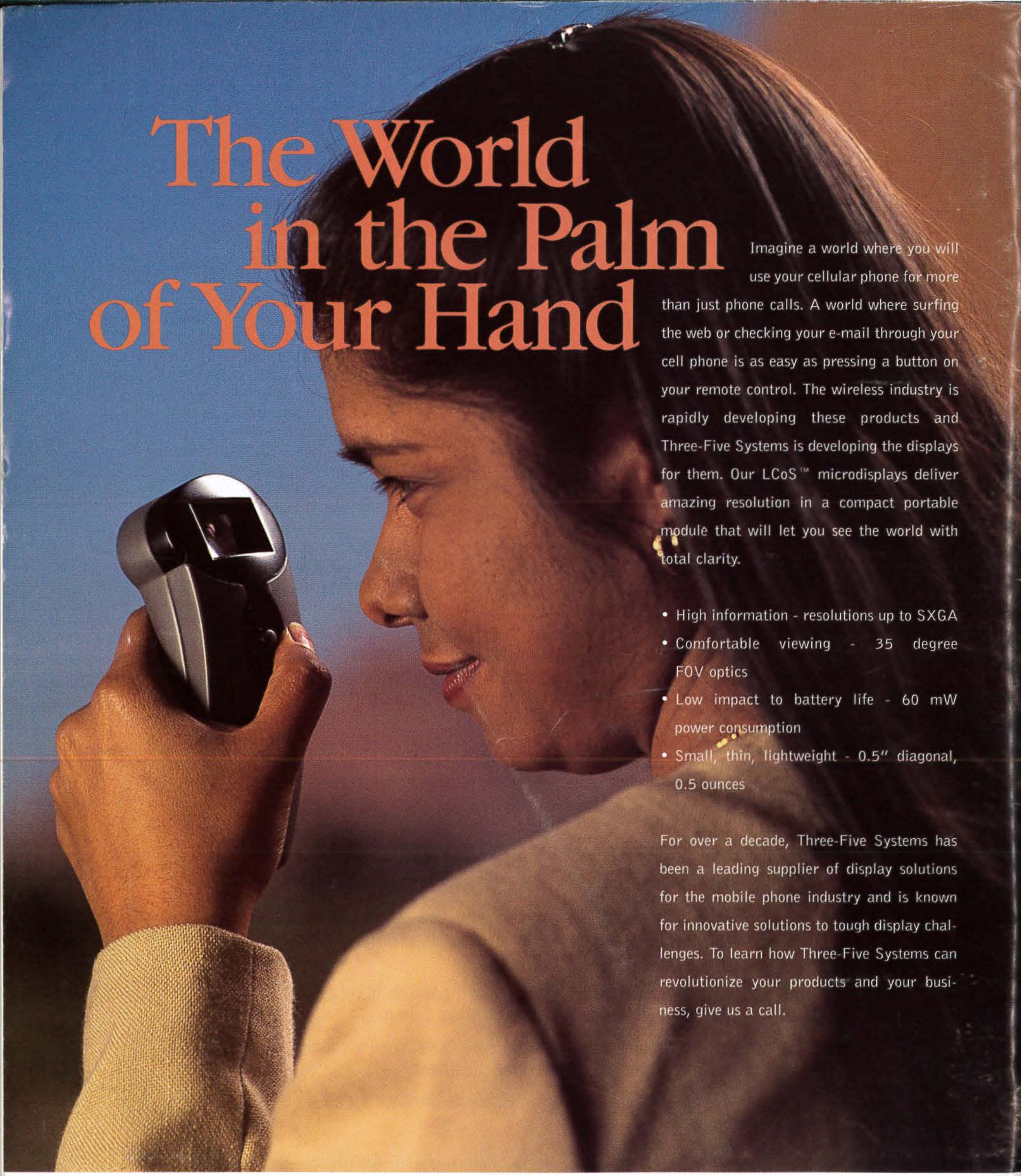
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