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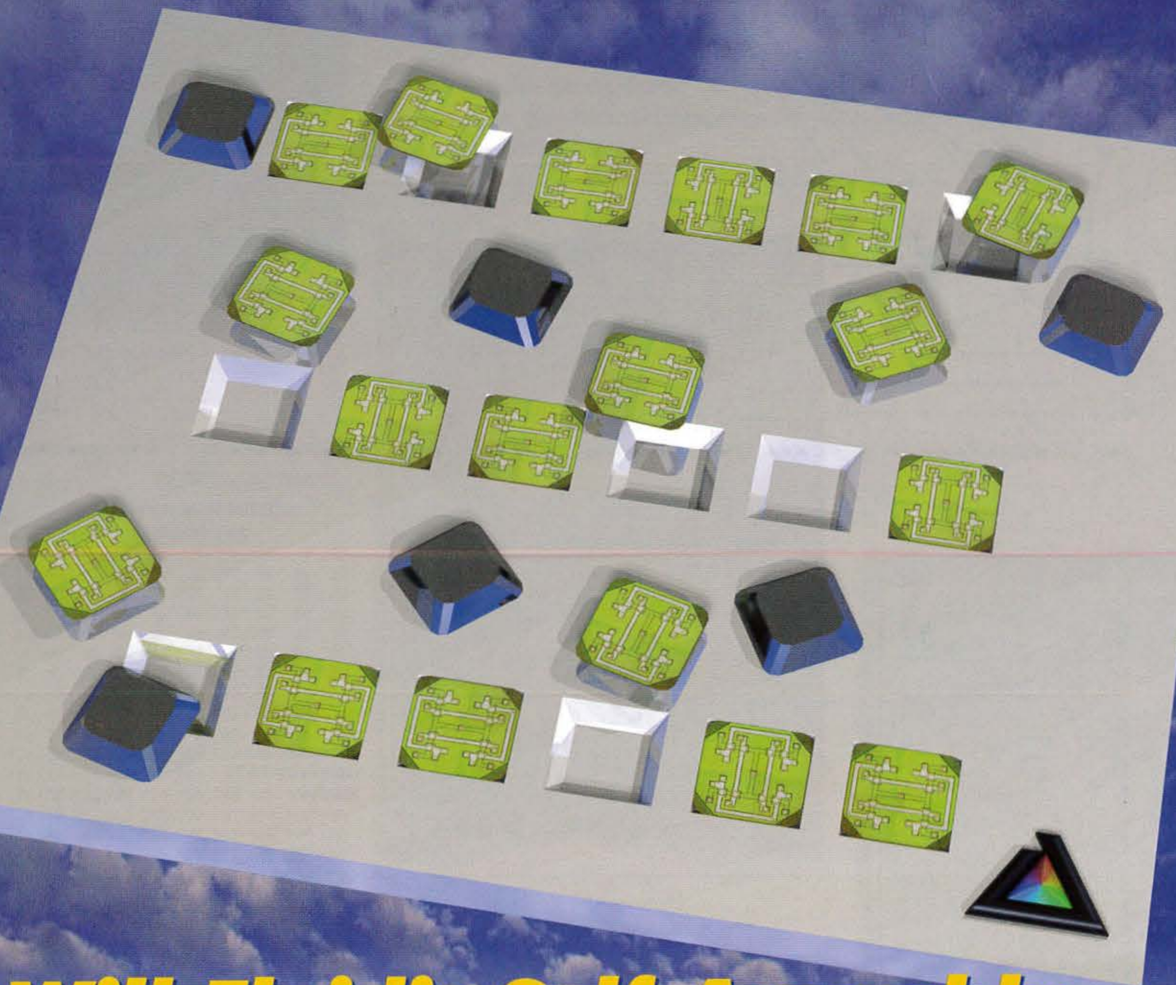

Will Fluidic Self-Assembly Replace TFTs?

- Fluidic Self-Assembly
- Laser Glass Cutting
- Phosphor Requirements
- Display Developments in Russia
- Taiwan's Growing FPD Industry

COVER: Alien Technology's fluidic self-assembly (FSA) washes IC-containing NanoBlock™ devices into matching depressions on a display back plate, as shown in this artist's rendering. The devices are separated from a standard CMOS wafer, so they are made of single-crystal silicon that can be used to realize pixel switches, drivers, and system electronics. Will FSA replace TFTs? See the article beginning on page 12.

Alien Technology

For more on what's coming in *Information Display,* and for other news on information-display technology, check the SID Web site on the World Wide Web: **http://www.sid.org**.

Next Month in
Information Display

Display of the Year Awards Issue

- The Best of '99
- Electronic Projection
- NIST Color Calibration
- AMLCD Medical-Imaging Systems
- Fewer Pixels; Equal Quality

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editorial

Paradigm Shift

During the process of selecting this year's *SID/Information Display* Display of the Year Awards, a distinguished member of the Display of the Year Awards Committee – who might prefer that his name not be mentioned in this context – implied with tongue in cheek (I think) that all direct-view displays represent "dead-end technology." (Does this mean that no direct-view displays will win Display of the Year Awards? To find out, I'm afraid you will have to wait until December to learn the results from *Information Display*'s Display of the Year Awards Issue or from one of the other publications that report on the awards.)

But my distinguished colleague was making an interesting point. Should we be trying to think the unthinkable? Whenever we envision a display-containing product, should we force ourselves to re-imagine that product with a display that is not a direct-view display? And what's left if we eliminate traditional direct-view displays from this imaginative exercise: only virtual displays (small displays viewed through an optical system), projection displays, eyeglass and head-mounted displays, and retinal displays that sweep a modulated collimated light source across the retina to create an image.

Would people accept a high-quality HMD – a descendent of the Sony Glasstron, perhaps – as their primary TV display? My friend Tom Holzel would like to believe that the new paradigm consists of very lightweight eyeglass-type displays. Should a portable computer be of Palm Pilot size, with one of Tom's wearable displays and voice input? Or will it be microdisplay-based rear-projection displays that make large-screen direct-view TV receivers, computer monitors, and even direct-view avionic AMLCDs obsolete?

This issue of *ID* contains an article from Alien Technology describing a paradigm-busting way of making active-matrix flat-panel displays with single-crystal pixel switches and the option of single-crystal on-board drivers and system electronics. But the displays are direct-view. Could this new manufacturing paradigm be derailed by new paradigms in display applications? Or could it go the other way, with the new manufacturing paradigm cutting costs and renewing the attractiveness of the old display paradigm?

Of course, the problem with thinking the unthinkable is not only that it's unthinkable. It may also be, at least in part, wrong. It may be that the babble of 400 people dictating to their Palm Pilots on a Boeing 747 will not be socially acceptable. And if people find they need a keyboard-sized input device, then they may also wish to stick with a direct-view display of similar size.

And some people may enjoy the social aspects of sharing a single television screen and a single visual space with family or friends. (Sharing a visual space with your beer and chips might also save some wear and tear on the carpet.)

I hope you weren't expecting a tidy conclusion to this editorial. I don't have one, but I'm not ready to kiss the direct-view display good-bye, either. Before consumers, even a significant minority of them, will abandon direct-view displays, they will have to see something that works better for them in a particular application. In some cases, they will find a better paradigm, and in some cases, I think, they won't. But since we in the display industry have not yet, relatively speaking, put a great many displays out on the market that try to solve consumer problems with non-direct-view displays, it's too early to either cheer or worry.

The year 2000, appropriately, is likely to provide the first serious testing of the waters.

– KIW

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Investment Advice ...

by Aris Silzars

Once upon a time, in a world before e-mail and the Internet, when the warm glow of vacuum tubes in radios, B&W television sets, and first-generation high-fidelity systems was sufficient to take the chill off a modest-sized living room on a cool fall evening, there came into being a few new businesses founded by highly capable people with names such as Hewlett, Vollum, and Varian who believed in the future of this technology and in the excellence and quality of the products they could create. They built their companies on integrity and solid technical and financial accomplishments. Others soon emulated their success and eventually spawned entire geographic regions of intense technological activity.

As these companies grew and prospered, there eventually came a time when it was no longer possible to support the rapid growth from the companies' own profits. Thus, to raise the additional capital needed to support their growth, the companies decided to "go public." This was not always a happy decision. Being a public company brings with it many constraints and loss of management autonomy. Nevertheless, the benefits of faster growth usually outweighed the desire of the founders to retain autonomy and control.

Of course, by the time the decision was made to seek additional resources through the stock market, these were all well-established and profitable businesses. Investors could readily assess the value of each company based on a track record of sales and profit performance spanning a number of years. The world of finance was relatively predictable and followed the rules of traditional economics. That is not to say that all was perfect, since overall growth and recession cycles still could and did have a significant influence.

Then, about twenty years ago, some enterprising folks in some newly created bio-tech businesses had a *really creative idea.* Why not go public on the *promise* of future success? After all, who needs to have a real product and real profits? If the future potential is sufficiently great, maybe people would buy into the company even if it had no sales and no profits. Then there would be even more money for new product development. And, by the way, they also figured out that the founders would get a nice share of this wealth sooner and without having to do all that nasty product-selling and showing-profitability stuff.

And it came to pass that times were good and this approach succeeded beyond most people's expectations. Furthermore, the eventual failure of most of these companies only dampened the spirits of investors in certain narrow market sectors. If bio-tech didn't seem to be working, then how about a new drug to cure the common cold? How about that company promising a new software program? Well, if that doesn't work, then how about that new Internet enterprise?

In this new and exciting world of high-risk finance, it is no longer necessary to show sales and profits. It is also no longer necessary to have a product. It is only necessary to have the *appearance of great future products.* In a form never contemplated, we have achieved the "virtual" corporation. This virtual corporation doesn't produce a product. It has no sales. It lives off other people's money. Its founders become rich. Its major and sometimes sole objective becomes moving wealth from one group of people to another. And I suppose, depending on who populates each group, this may not be an entirely bad objective.

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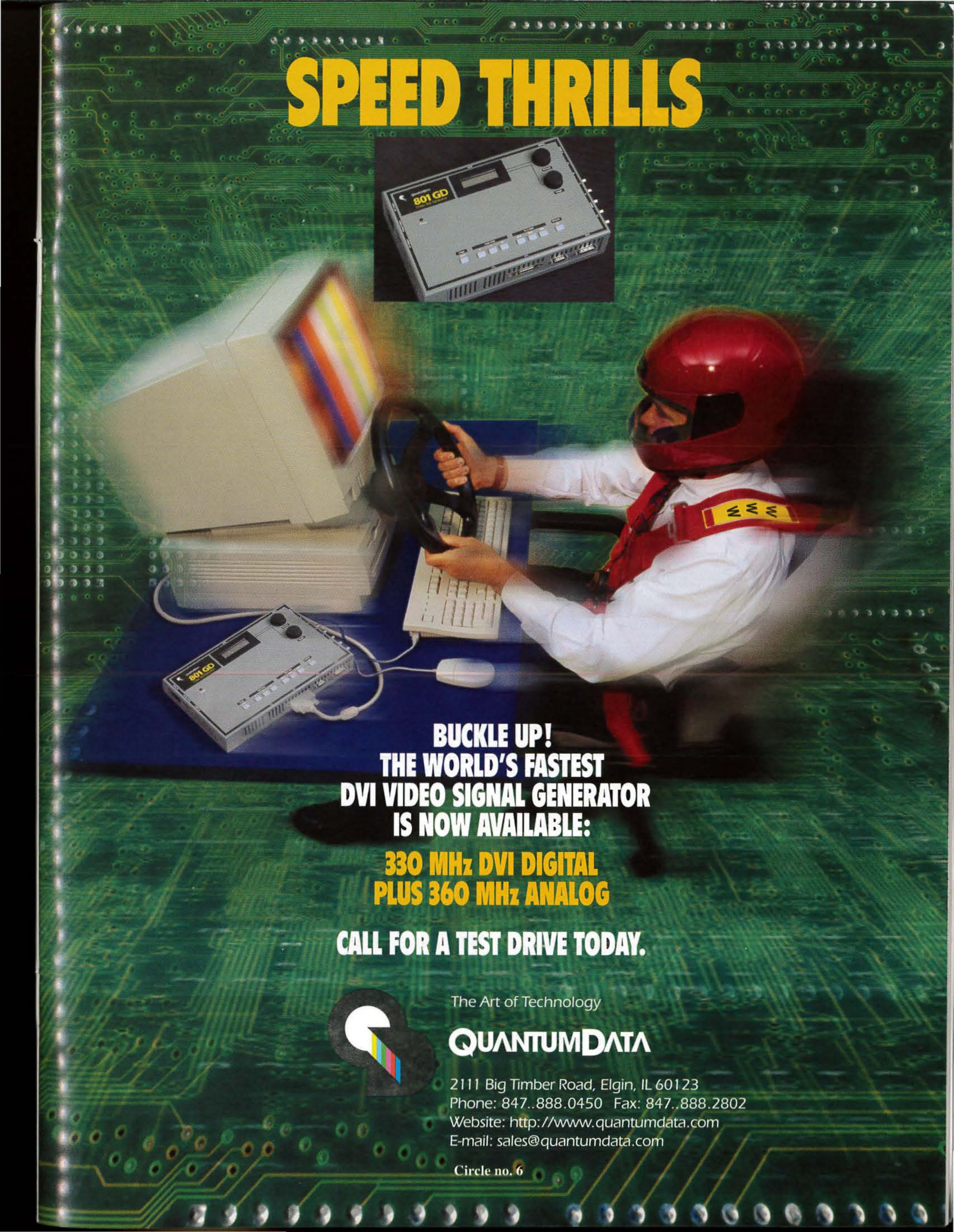
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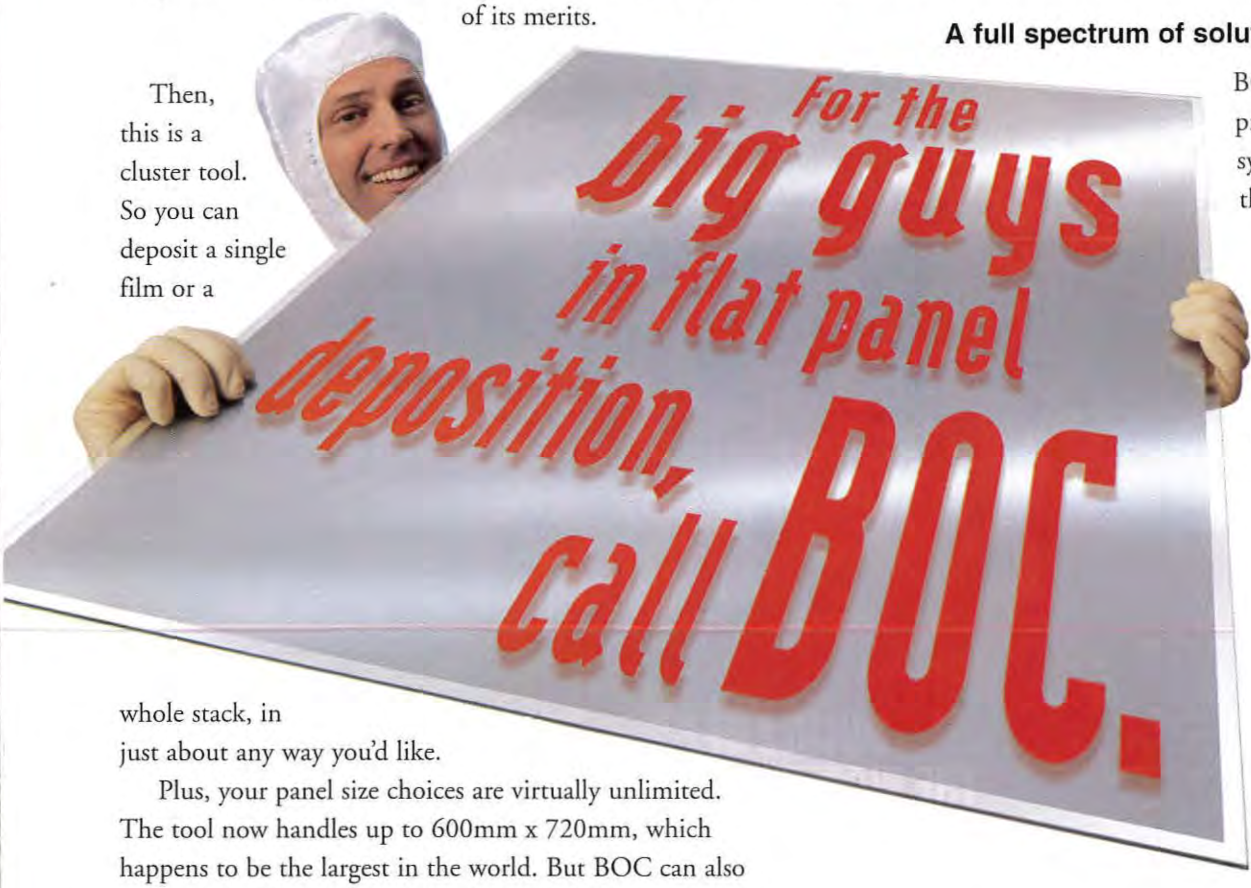

Then, this is a cluster tool. So you can deposit a single film or a whole stack, in just about any way you'd like.

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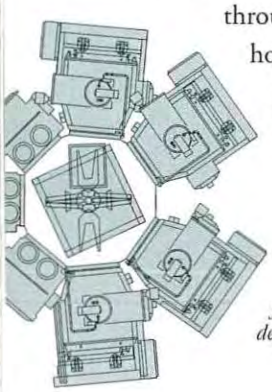

Designed for production, BOC's flexible cluster configuration lets you deposit a single film or an entire stack.

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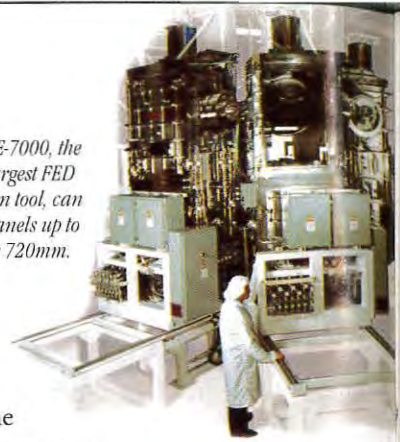

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Fluidic Self-Assembly Could Change the Way FPDs Are Made

A new way of incorporating single-crystal-silicon pixel switches, drivers, and system electronics in virtually any FPD back plate could create cheaper, better-performing displays.

by Stan Drobac

TODAY's active-matrix liquid-crystal display (AMLCD) is an impressive example of engineering and manufacturing prowess. Decades of R&D and billions of dollars of investment have resulted in an industry that can produce a fundamentally complex product at a cost acceptable to some relatively high-volume markets. Producers have learned to fabricate amorphous-silicon (a-Si) and polysilicon (poly-Si) transistors, to handle ever-larger sheets of glass, and to perform difficult assembly operations with high yield.

Still, current AMLCD manufacturing is characterized by some painful compromises. Transistors, for example, are large and limited in performance because they are usually fabricated from a-Si deposited on glass. Even low-temperature-polysilicon (LTPS) transistors are large and have poor characteristics compared to those made in even the simplest commodity IC processes. As a result, displays need either expensive TAB-mounted driver circuits (for a-Si) or added processing with attendant yield loss (for LTPS). In either case, it is not possible to build much, if any, intelligence into the display matrix.

Another compromise is that of the glass substrate itself. Glass is transparent and can tolerate the processing temperatures and chemicals needed to produce a-Si and LTPS transistors, but it presents a difficult and costly handling challenge, especially as panel sizes grow. The resulting end product is a display that can look good but is easily broken.

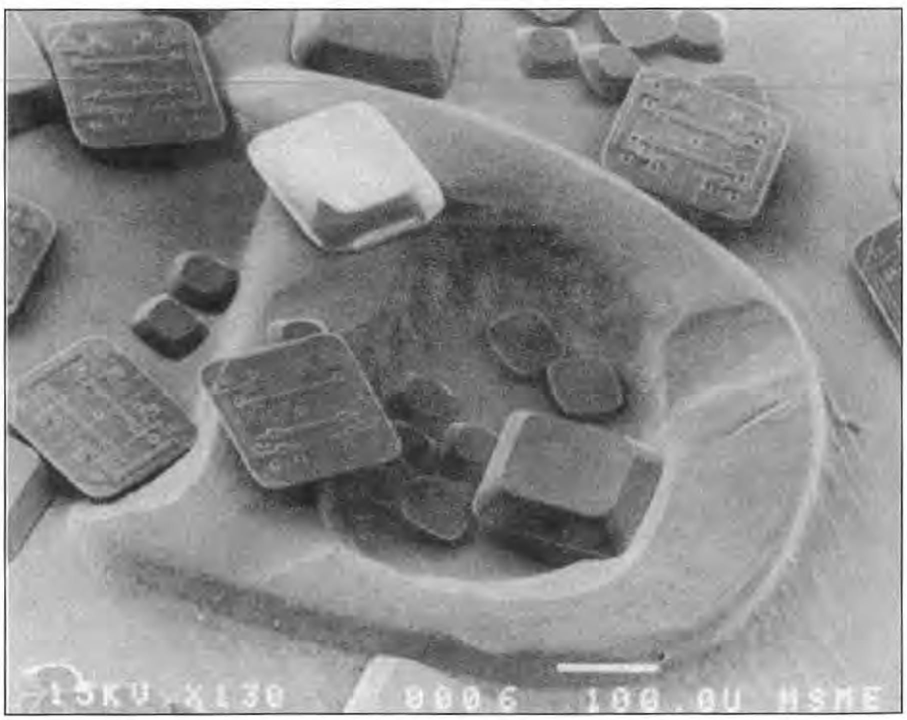

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Fig. 1: *These NanoBlocks used in fluidic self-assembly (FSA) are "tested-good" ICs separated from a CMOS wafer which can range from ten to several hundred microns square. They are shown here in and around the "D" on a U.S. dime.*

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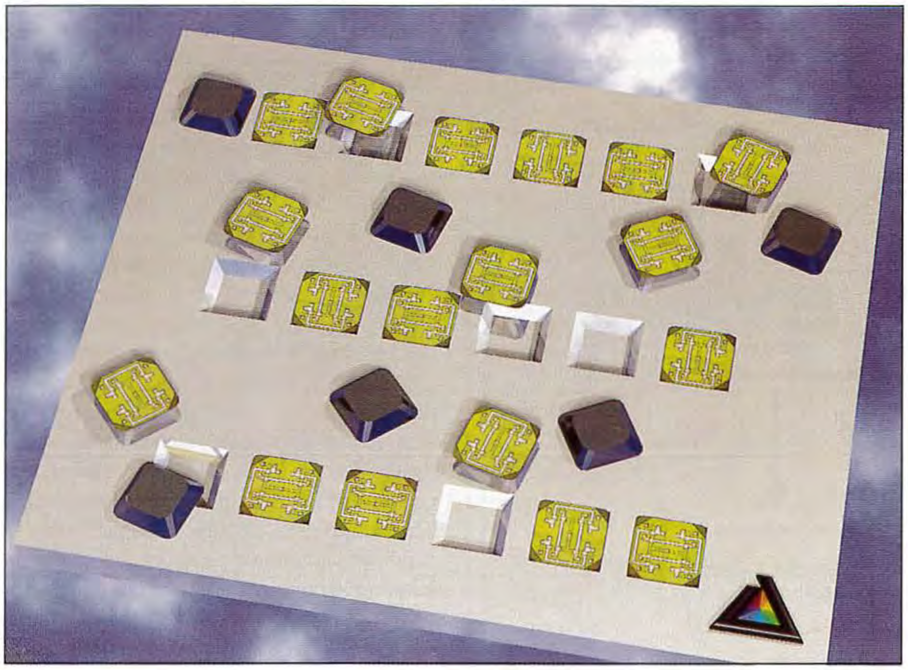

Fig. 2: *In this artist's rendition, NanoBlocks are falling into the matching holes in a substrate.*

A long-held industry goal has been to move display manufacture away from glass to flexible plastic substrates. Doing so could allow the use of high-productivity roll-to-roll processing and enable the production of thinner, lighter, more robust displays. However, plastic substrates sharply limit processing temperatures, making transistor fabrication substantially more difficult. A few researchers have been able to produce functional transistors on plastic, but the high-volume fabrication of plastic-substrate AMLCDs is not likely to be viable in the near future with existing methods.

Fluidic Self-Assembly

An alternative to the traditional approach of transistor fabrication *in situ* on a glass substrate has been developed by Alien Technology Corp. Fluidic self-assembly (FSA) decouples the production of transistors from the processing of the display materials, eliminating the need for expensive fabs capable of producing transistors directly on a sheet of display glass. FSA allows the accurate deposition of known good semiconductor devices over large rigid or flexible surfaces to within ±1 micron. As a result, the fabrication of devices for an active-matrix backplane can be outsourced to commercial IC foundries.

FSA can be used to produce display backplanes on rigid (glass or plastic) or flexible (polyester, polyimide, polycarbonate, *etc.*) substrates. We at Alien are convinced that

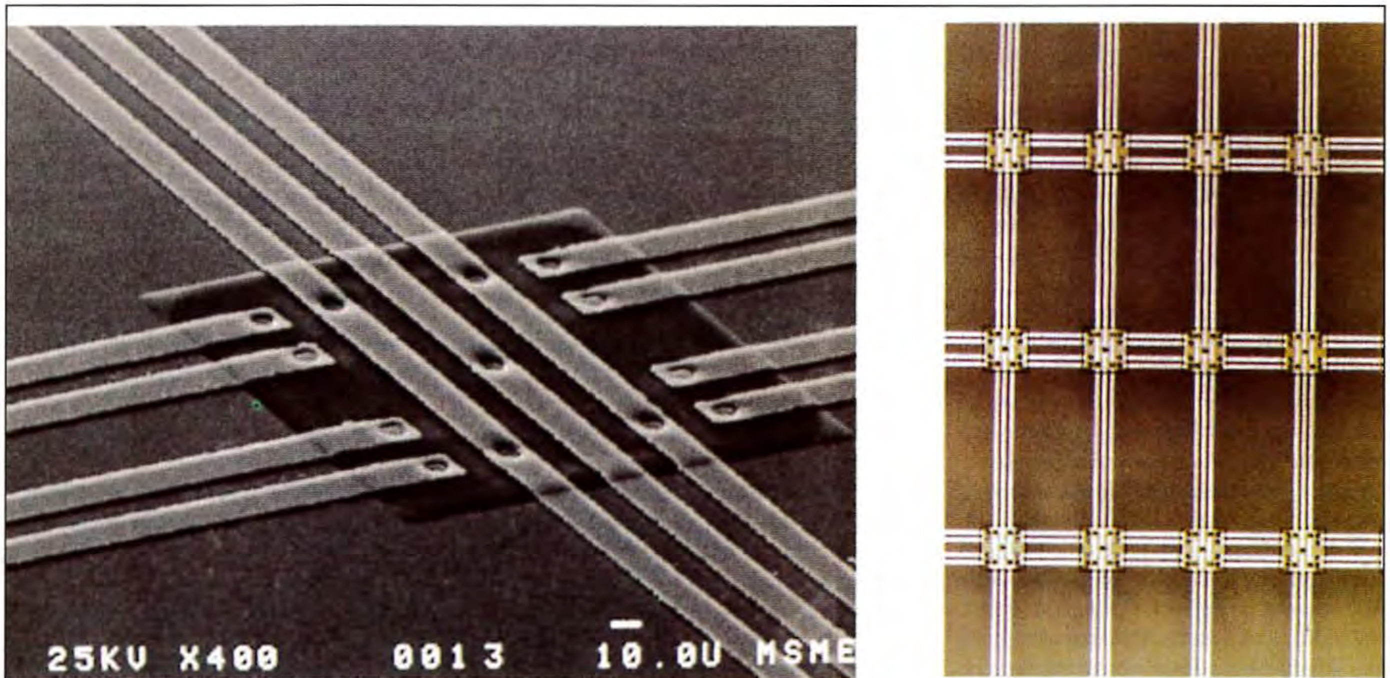

Fig. 3: *The FSA process recycles excess NanoBlocks and reuses the suspension fluid.*

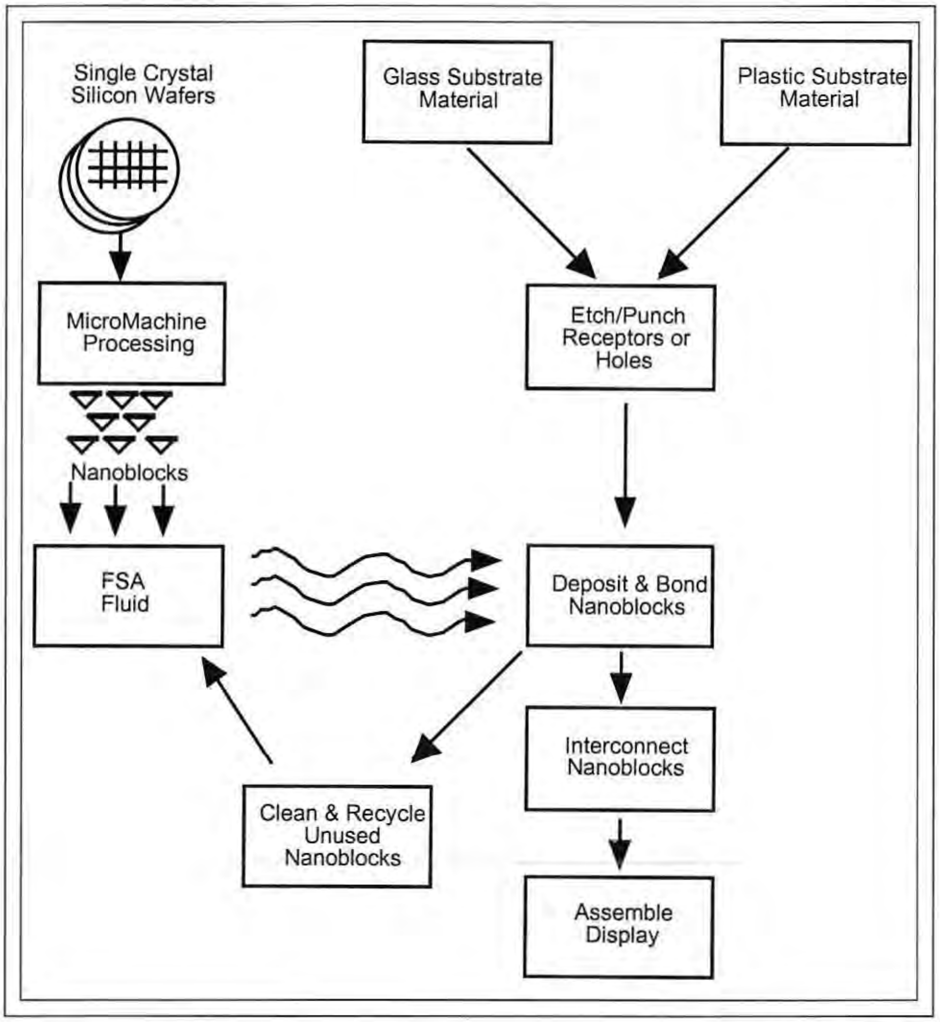

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Fig. 4: *After FSA, the passivated NanoBlocks are metallized and interconnected as (a) a single metallized Nanoblock and (b) a 3 × 4 array.*

such backplanes, built of devices from standard IC processes, can lower the cost and enhance the performance of essentially all flat-panel-display (FPD) technologies, including promising new display technologies such as organic light-emitting diodes (OLEDs).

FSA promises to accelerate the transition to fully automated in-line roll-to-roll (web) processing on a continuous flexible substrate. Web processing is a high-volume continuous technique, much more efficient than the batch-oriented processes used in existing AMLCD fabs. Together, FSA and web processing promise to reduce manufacturing-facility investment, reduce materials and manufacturing costs, increase manufacturing throughput and yield, increase manufacturing-line flexibility, and provide the potential for making very large lightweight displays.

What Is FSA?

The basic principles behind FSA are simple. In the FSA process, specifically shaped semiconductor devices, ranging in size from 10 microns to several hundred microns square, are suspended in liquid and flowed over a surface that has correspondingly shaped depressions on it into which the devices settle. The shapes of the devices and depressions are designed so the devices fall easily into place and are self-aligning.

The process begins with a single-crystal-silicon wafer containing anywhere from hundreds to millions of microelectronic devices. The devices can be as simple as individual transistors or as complex as integrated circuits (ICs). Alien uses large commercial semiconductor foundries to produce these microelectronic devices using standard CMOS IC processes.

In the next step, each separate microelectronic device is freed from the wafers through an etching process that separates the silicon wafer into thousands or millions of separate functional devices having specific three-dimensional shapes (Fig. 1). Alien has trademarked the term "NanoBlock" to describe the devices freed from the silicon wafers.

Separately, the display backplate – to which the NanoBlocks will be bonded – has depressions stamped, punched, etched, or laser-drilled into it. These specifically shaped holes correspond to the shapes of the NanoBlocks. The NanoBlocks are then suspended in a fluid, which is flowed across a previously prepared substrate surface. As the NanoBlocks pass over the substrate surface, they drop into the correspondingly shaped holes (Fig. 2).

It is this step that is the heart of the process. It allows all of the semiconductor circuitry for an active-matrix display to be produced in IC fabs. It also gives the display manufacturer the freedom to select flexible substrates and web processing, and to enjoy the performance of single-crystal silicon, which is substantially greater than that of a-Si and poly-Si.

The NanoBlocks that do not assemble themselves into holes in the substrate surface are removed from the fluid, cleaned, and re-suspended in cleaned fluid to be flowed over another substrate. In this way the NanoBlocks and suspension fluid are recycled (Fig. 3).

In the last step, the NanoBlocks that did self-assemble into the holes in the substrate are electrically connected via standard metallization techniques (Fig. 4) to create the final integrated system – in this case, an active-matrix display with fully integrated on-board drive and control logic.

Because NanoBlocks are tested before separation from the silicon wafer, all NanoBlocks that enter the FSA process are "tested-good" devices, which should result in high manufacturing yields and high-reliability displays. The NanoBlocks can be designed with redundant active devices and redundant row- and column-drive circuitry for backup should one of the devices later become inoperable.

The substrate into which NanoBlocks are assembled can be made from any number of rigid or flexible materials, including glass,

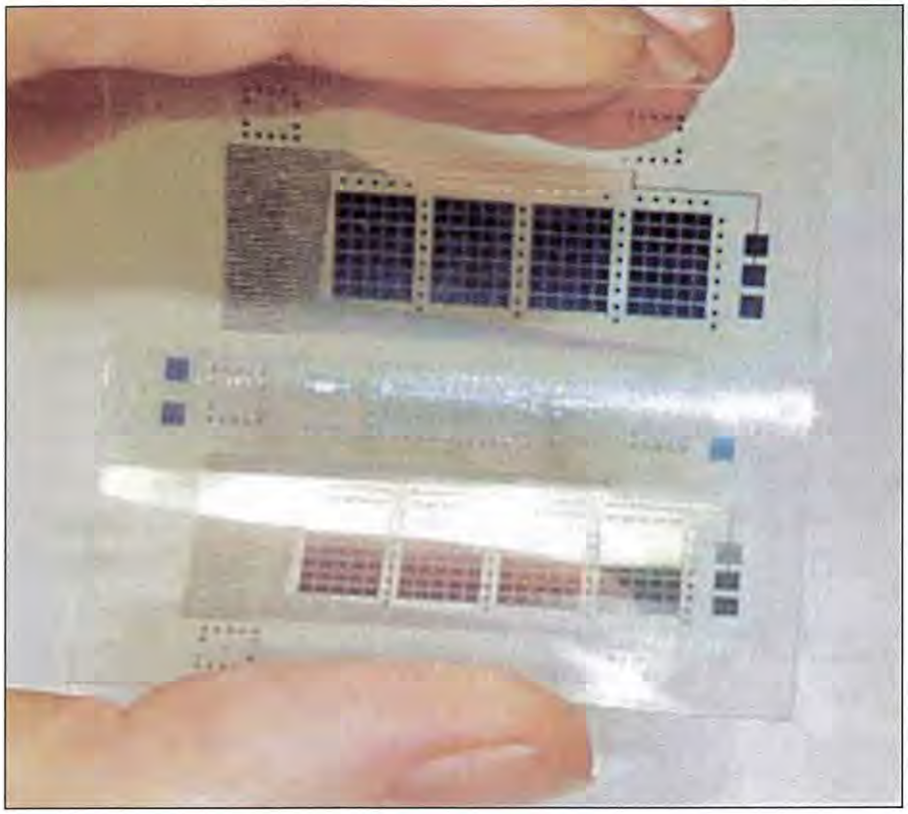

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Fig. 5: This demonstration display was built on a PET substrate using single-crystal-silicon NanoBlocks and sputtered aluminum interconnects. The display is a PDLC/ITO/PET laminate.

plastic, and silicon. The NanoBlocks themselves can be made so small that bending moments are not large enough to damage the blocks, even when they are mounted in a highly flexible substrate. This opens up the possibility of displays that can be flexed or bent while in use, and are light in weight.

FSA is a fast process for placing from dozens to millions of microelectronic devices into an array. Substrate-fill experiments indicate that arbitrarily large substrates can be completely filled in a few minutes at most.

NanoBlocks can be fabricated in numerous materials, such as silicon, silicon-germanium, gallium arsenide, or indium gallium phosphide, depending on desired functionality. NanoBlocks of differing sizes, shapes, materials, and functionality can be mixed and matched on a substrate using the FSA process, and because submicron IC technologies can be used, the Nanoblocks can incorporate significant circuitry while still consuming less space than individual a-Si or poly-Si transistors.

Applications

FSA promises to be an effective complement to some promising new display technologies. OLED displays, for instance, could be attractive for making wall-hung roll-up displays, but they require active-matrix drive characteristics that a-Si and poly-Si processes cannot easily provide. FSA, using single-crystal-silicon NanoBlocks, could make large-screen active-matrix OLEDs practical.

Plasma displays may also benefit from FSA. With FSA, an active-matrix backplane for a plasma display could be made using pixel transistors built on a standard high-voltage IC process. With such a backplane, high voltage could be switched locally at the pixel at high speed with optimized characteristics. This could dramatically reduce the panel's power consumption and simplify its design.

LED displays could also be produced more economically with FSA. A single LED wafer could be micromachined into tens or hundreds of thousands of LED NanoBlocks and placed onto a suitable substrate using FSA. This would create an LED display array, which is prohibitively expensive to build with existing techniques.

FSA applications are not limited to FPDs. Other possibilities include large-scale sensor arrays and mixed-technology electronic circuits - such as laser devices assembled into silicon circuits to provide optical interconnects. As a cost-effective solution to the problem of creating large-area fine-scale assemblies, FSA has a large number of manufacturing applications.

Where Are We Now?

The FSA process has been proven on small substrates. Substrate fills into a 3-in.-square substrate with 11,000 NanoBlock sites show consistent 100% fills, *i.e.,* no missing or misaligned blocks - in 30-60 sec. We believe that the process is easily scalable and capable of filling much larger substrates in about the same amount of time. (We intend to have production FSA equipment made with multiple NanoBlock sources spread across the substrate area, akin to watering a lawn with an array of sprinkler heads.)

The subsequent process steps of depositing metal over the NanoBlocks and patterning interconnects to produce a functional active matrix have also been successfully demonstrated. Flexible demonstration displays with 140 pixels have been produced on a PET substrate using a polymer-dispersed liquid-crystal (PDLC) display material (Fig. 5).

Alien's Business Strategy

The obvious initial application for FSA is to simply drop it into an existing AMLCD process, eliminating all of the steps required to fabricate a-Si or LTPS transistors. Indeed, Alien has begun work with one major AMLCD manufacturer and is in discussion with others who are interested in using FSA in their existing glass-panel fabs.

Alien itself intends to establish a roll-to-roll production facility to build displays on flexible substrates. In contrast to some other start-ups, Alien will initiate production with the smallest, simplest displays possible. (Unlike many other new technologies, whose cost structures typically mandate a high-end market entry, the combination of FSA with web processing will give Alien a cost structure that supports low-end consumer-product pricing.) This will allow the early development of a high-volume production infrastructure with minimal execution risk. The company's initial product, to begin sampling in late 2000, will be a small, flexible monochrome display for smart cards. Smart cards represent a large potential market that has not yet been served because of the difficulty and cost of producing a robust flexible display by conventional techniques. Alien is already engaged with initial customers in that market, and plans to ship millions of smart-card displays in 2001.

Over time, Alien intends to expand its product range to increasingly complex displays covering many kinds of portable devices and, later, larger displays for computer, TV, and other applications. ■

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The Future of Laser Glass Cutting

Laser glass cutting is now a viable production process with clear benefits – particularly for high-value displays offering opportunities for downstream process savings.

by Brian Hoekstra

MANY CRITICS might claim that - like the laser itself 20 years ago - the laser cutting of glass represents an invention still in search of an application. While there is no doubt that laser cutting of glass is a commercially viable process, the question remains, why hasn't laser cutting replaced mechanical methods? The two major reasons are cost and market acceptance.

In reality, laser cutting may not replace mechanical methods for some applications. Laser cutting will, however, prosper in markets where it provides a decided cost advantage or quality advantage, or turns out to be an enabling technology. The key to realizing this potential - as with any new technology - is acceptance by the industry.

Gone are the days of smoke and mirrors. The technology is here and continues to improve every day. The quality of laser-cut glass is far superior to mechanically cut glass, no matter how one chooses to measure "quality." The feedback from customers ranges from astonishment to excitement as more and more new applications are discovered. As with most new technologies, they reach a certain level of maturity; however, the concerns seem to be shifting from technical feasibility to production, cost, and reliability.

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The success of any pioneering technology depends on early adopters: forward-thinking customers who are willing to make a commitment and endure the risk. Before these new users are willing to take that risk, they must be confident about the reliability of the process and equipment. One way to produce this confidence is by cutting and analyzing actual samples to highlight the benefits of laser glass separation. Another way is to provide a clear and concise explanation of the current state of the technology - and of future improvements - so that customers can make informed decisions about laser glass cutting. This article is an attempt to provide such an explanation.

Background

The laser cutting of glass is a high-tech solution to a relatively low-tech problem: how to make a number of little pieces of glass out of one large piece of glass. This process is important in many areas, but perhaps most important to active-matrix LCD (AMLCD) manufacturers, who routinely must fabricate several displays on a single glass substrate. The traditional method of separation relies on mechanical scribe-and-break techniques that have been around for literally thousands of years.

About 40 years ago, scientists discovered that a laser could be used to cut glass by melting and ablating the glass. Then, about 30 years ago, laser heating and quenching methods were developed in the U.S. This method creates a thermal shock in the glass that effectively breaks the molecular bonds without removing any material. Laser cutting, for the purposes of this discussion, involves the controlled propagation of a microcrack through a glass substrate. While this technique has been around since the early '70s, recent increases in processing speeds and single-pass separation techniques have helped make the process commercially viable.

Full-Separation Technology

In June of 1997, Accudyne Corp. received a contract - funded by the United States Display Consortium (USDC) - for an effort entitled "Advanced Glass Separation." Originally, the USDC contract called for the development of a laser scribe tool and a separate break tool. However, shortly after this author joined the USDC team in February of 1998, the USDC scientists and engineers developed innovative techniques for single-pass separation, eliminating the separate breaking step. As a result, the USDC technical review team recommended building two identical units that would perform both of these steps in a single tool. This full-separation technology represents a significant breakthrough in the quality of the cuts, as well as in throughput and cost of ownership (Fig. 1).

When compared to traditional mechanical processes, laser cutting offers a wide range of advantages:

- ***Faster speeds*** of up to 1000 mm/sec increase throughput.
- ***Single-pass separation*** improves throughput and is a non-contact method.
- ***Improved edge quality*** increases yields.
- ***Cleanroom certification*** improves device yield for open surfaces.

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Accudyne Corp.

Fig. 1: *A typical laser-cut edge is cleaner and more strain-free than a mechanically cut edge.*

- ***Reduced cost of ownership*** eliminates the equipment required for downstream processes such as edge seaming, cleaning, and edge grinding.
- ***Reduced cleanroom floor space*** because fewer machines are required.
- ***More efficient use of substrates*** enables unique device layout, and saves glass real estate due to the elimination of kerf.

USDC Beta Units

The full-separation technology has been incorporated into the two USDC laser-cutting beta units that are currently being field-tested (Fig. 2). The first USDC beta unit was installed at Planar Systems in Beaverton, Oregon, where it recently underwent production testing. The second beta unit was used for process demonstration and sample preparation at Accudyne Display and Semiconductor Systems in Palm Bay, Florida, before being shipped to Three Five Systems in the fall of 1999. A third research unit is being upgraded and readied for sample cutting, and several new commercial units are being designed and readied for sale.

Production Testing

In May of 1999, Planar Systems performed a number of production runs in order to assess the equipment and technology under actual production conditions. The yield increased on each of five successive production tests, culminating in a final production-run yield of 99.5% on OA-2 glass designed for electroluminescent (EL) devices. The throughput for this test averaged 37.5 panels, or 75 parts per hour. The exercise resulted in many lessons learned, and established laser glass cutting as a viable contender for use in production. The opportunity to test the equipment under actual production conditions with real parts proved to be invaluable.

AMLCD Applications

Laser cutting can be more expensive than mechanical processes; as a result, it is better suited at this point for some applications than others. If a company makes thousands upon thousands of 5-cent parts, then a laser-cutting system – no matter how superior the quality of its cuts – probably cannot be justified even with the most liberal cost-of-ownership model. If the parts are expensive, however, and a small improvement in yield can have a large financial impact – as is the case with AMLCD panels – then it is easier to justify the added cost of a laser-cutting system (Fig. 3).

Commercialization of laser-cutting systems is inevitable – it's just a matter of when and by whom. Currently, the major players in laser-glass-cutting systems are Schott Glass in Germany, Mitsuboshi Diamond Company in Japan, and Accudyne DSS in the U.S. Schott Glass has limited its applications to in-house and generic glass-cutting applications in Europe for the most part. As of this writing, they have yet to make a serious entry into the AMLCD marketplace. Mitsuboshi has been in the mechanical scribe-and-break business for years, and is now attempting to add laser cutting to its portfolio. Accudyne engineers developed a new approach and successfully developed it into a commercial technology. This author, in conjunction with scientists from the University of Central Florida, have since developed and perfected laser cutting for production use. As a result, patent applications have been filed to protect this new technology. And the race is on.

Other Applications

In addition to potential cost savings, laser cutting can provide additional advantages over mechanical techniques for some applications. For example, several glass-mounted biological samples might need to be separated without touching the surface in order to avoid contamination. Some production processes may require cleanroom environments, such as cutting of glass with open surfaces and active areas. Accordingly, the USDC tool has been designed and certified to operate in Class 10 cleanroom environments. This makes it possible to cut the glass prior to assembly of the cells, which gives the manufacturer more product-flow options.

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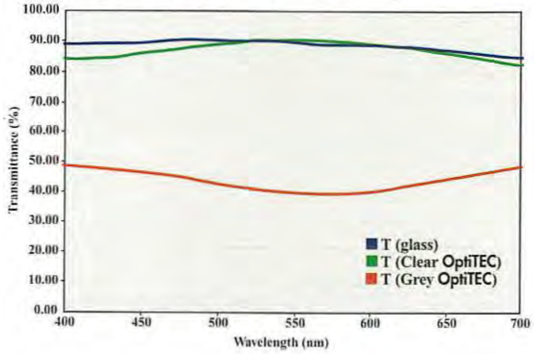

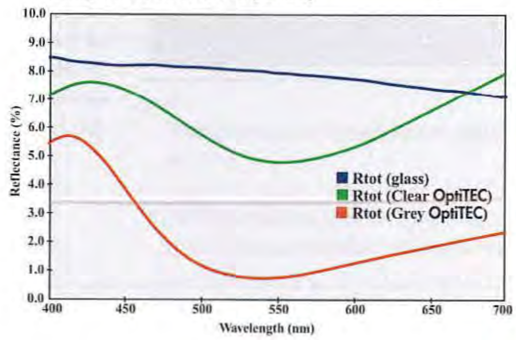

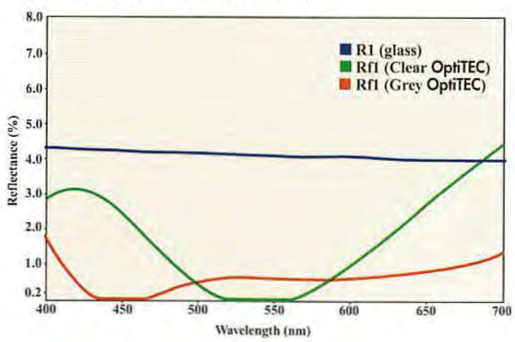

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Product	Total Reflectance	Total Transmittance	Sheet Resistance
	(%)	(%)	(ohms/square)
Clear OptiTEC	<5.3	89.5 +/– 1.0	<250
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Fig. 2: The LC-650 beta laser cutting tool was developed under a contract with the United States Display Consortium.

Laser cutting makes edge cutting of minimal size possible (Fig. 4). In theory, this could permit an AMLCD manufacturer to fabricate larger panels on a given-size substrate by reducing the waste area. Since no material is removed by the process and there is no kerf, one can literally cut between pixels on a display, leaving each side undisturbed and undamaged. This could make it possible to tile panels with seamless boundaries between the tiles, resulting in the appearance of a single contiguous large panel.

Market Summary

A number of markets already exist that can take advantage of the benefits offered by laser-cutting technology:

- Flat-panel-display (FPD) manufacturers, primarily AMLCD.
- Specialty applications: biological coatings, medical applications, and research and development.
- Glass singulation: architectural, automotive, and CCD cameras.

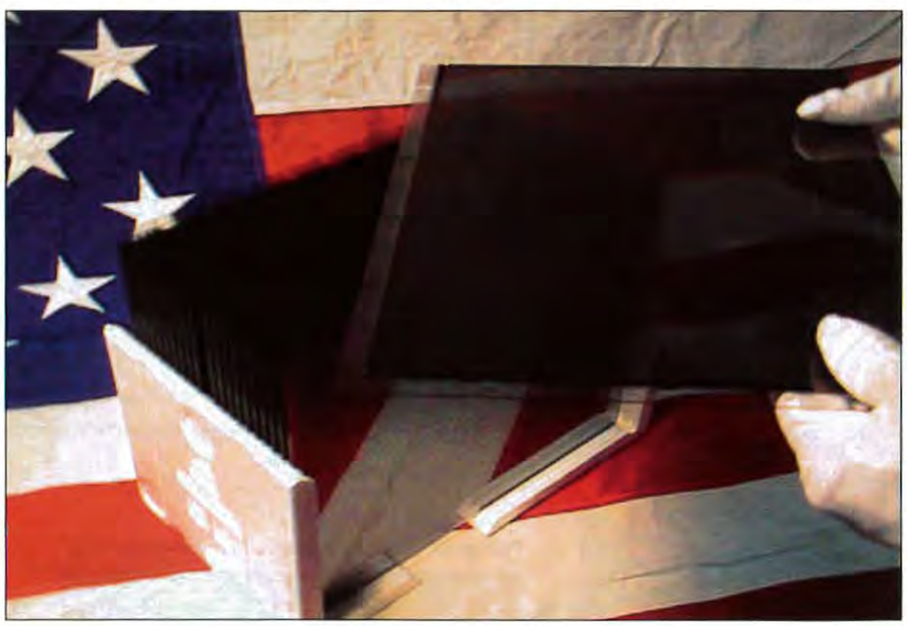
Manufacturers of AMLCDs are most likely to be the first to adopt this new technology because the end products are expensive, the capital budgets are large enough to support the purchase of process tools, and the technical resources are great enough to provide engineering and manufacturing support for converting to a leading-edge process. This market is currently limited to major Japanese, Korean, and Taiwanese companies. More specifically, our near-term focus will be to incorporate the technology into a production environment with a large AMLCD manufacturer such as Samsung Electronics in Korea. Laser cutting can work in existing fab lines, as well as newer lines for larger glass panels, and can play a part in automating production lines.

The U.S. market is expected to come along somewhat more slowly than the Asian market, and this technology will initially be used in specialty applications, stand-alone R&D units, and contract cutting of glass.

The Future

The laser-cutting market remains ripe for development, and considerable efforts have been made familiarizing the industry with this technology through word of mouth, technical papers, presentations, and the demonstration of the equipment at SID '98 and Display Works '99. While the reception of the technology has been enthusiastic, implementation has been slow for several reasons:

- Manufacturers are reluctant to convert from an accepted and proven - even if not ideal - mechanical separation process to an unproved method.



Samsung Electronics Corp.

Fig. 3: A variety of laser-cut AMLCDs have been produced.

Accudyne Corp.

Fig. 4: With laser cutting, it is possible to cut 1.0-mm-wide strips from 0.7-mm-thick Corning 1737 glass.

- The Asian economic flu has hampered AMLCD sales in Asia and indirectly affected sales in the U.S., reducing capital expenditures by manufacturers – although capital-equipment sales may be on the verge of picking up as this article goes to press.
- Manufacturers are still not completely aware of the capabilities and advantages of laser glass cutting because the technology has only recently been demonstrated to be viable.
- Limited production experience and a shortage of production glass has slowed efforts to bring the technology to market.

In order to overcome these challenges, steps are being taken to

- Develop a commercial in-line laser-cutting system designed to meet the demanding production requirements of AMLCD manufacturers.
- Spin-off USDC-funded laser-cutting technology to capitalize on the technological breakthroughs and market opportunities.
- Establish agreements and sales with major U.S. and Asian customers.
- Create partnerships with major U.S. and Asian companies to implement the technology.
- Secure private capital to meet market demand.
- Establish an after-sales support infrastructure both in the U.S. and Asia.
- Continue research and development on glass cutting and other production-related technologies.

There is no question that laser cutting of glass panels works, is a viable production process, and can offer significant advantages and savings. In spite of the challenges that lie ahead in the near term, it is only a matter of time until manufacturers see the light.

Acknowledgments

The author acknowledges Bob Pinnel at USDC, Arvi Kar at the University of Central Florida School of Optics, D. H. Choo at Samsung Electronics, and the USDC technical team comprising Candescent Technologies, Planar Systems, and Three Five Systems for their invaluable contributions to this work. ■

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Phosphor Requirements for FEDs and CRTs

Despite the interest in phosphor research for field-emission displays, FED phosphors and CRT phosphors have more in common than one might expect.

by Martin Kykta

WHETHER phosphors are being operated in a cathode-ray tube (CRT) or field-emission display (FED), they must be designed for optimum efficiency and the proper vacuum must be maintained. For both devices, the operating voltages, currents, and light output are intimately related. The phosphor's lifetime – the operating time over which the light output falls to half its initial value - follows the same rules regardless of whether the phosphor is placed in a CRT or FED.

A CRT typically has a vacuum of approximately 1×10^{-7} to prevent contamination of the cathode. Manufacturers achieve this vacuum by a multi-step process. First, the CRT is vacuum baked, operated, and then sealed. A barium getter, activated by evaporation, is utilized to trap contaminants that will outgas from the phosphor, cathode, and walls during operation - contaminants that would otherwise poison the cathode and degrade the phosphor. The usual phosphor-degradation contaminates are water, oxygen, and carbon dioxide.

It is easy to pump the CRT down, *i.e.*, establish a good vacuum inside it, because of its small surface-to-volume ratio. Nonetheless, the inside surface area available for applying the getter is large enough to allow a large ratio of active getter area to volume, which permits the CRT to maintain a good vacuum over its lifetime.

The FED also needs a good vacuum to maintain phosphor life, but the FED has the disadvantage of having a large surface-to-volume ratio. It is as difficult to pump between two closely spaced glass sheets as it is to suck soda from a glass with a squashed straw. Faster pumping speeds could be obtained by increasing the gap between the plates, but this would require a focusing grid to direct the electrons at the phosphor and make the current density more uniform. Applying an evap orable getter between the phosphor and cathode to assist in the pumping would interfere with FED operation. Placing a non-evaporable getter with a low activation temperature along the side could be the answer.

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Designing Phosphors for FEDs and CRTs

A CRT phosphor is applied to the inner surface of a glass tube in a polyvinyl alcohol (PVA) resin slurry. A pattern is made in the phosphor by UV photolithography. Phosphor screens that have 1.4 layers of phosphor particles produce the most light. If any more layers are added, the light produced in the first layers is scattered and absorbed in its path through the phosphor. In practice, two layers are put down to minimize manufacturing defects.

The phosphor-particle size determines screen resolution, and for most high-resolution CRT screens 4.5-μm-diameter particles are acceptable.[1] A thin conductive layer, usually aluminum, is evaporated over the phosphor after an organic film is deposited onto the phosphor coating to create a smooth surface for the aluminum. However, a very thin

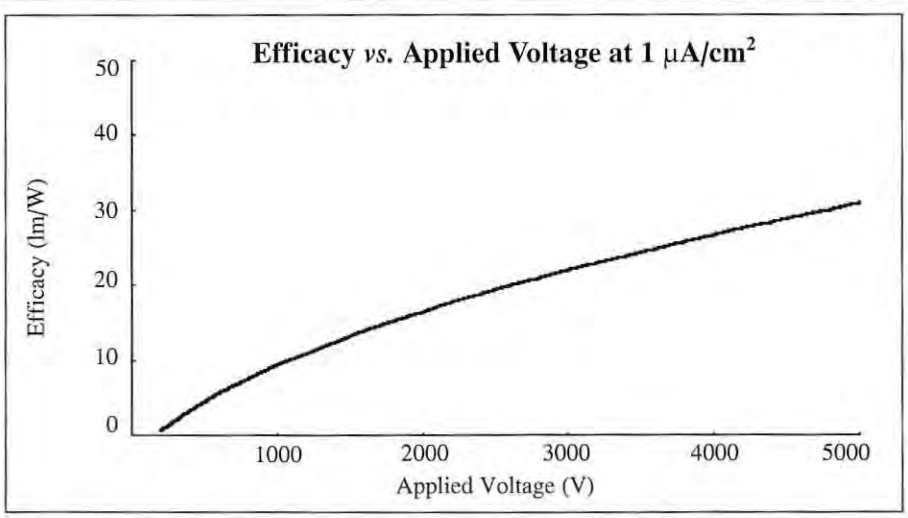

Fig 1: Calculated plot of the efficacy (lm/W) vs. *voltage for a green ZnCdS:Cu,Al phosphor with no aluminum layer operating at 1 μA/cm².*

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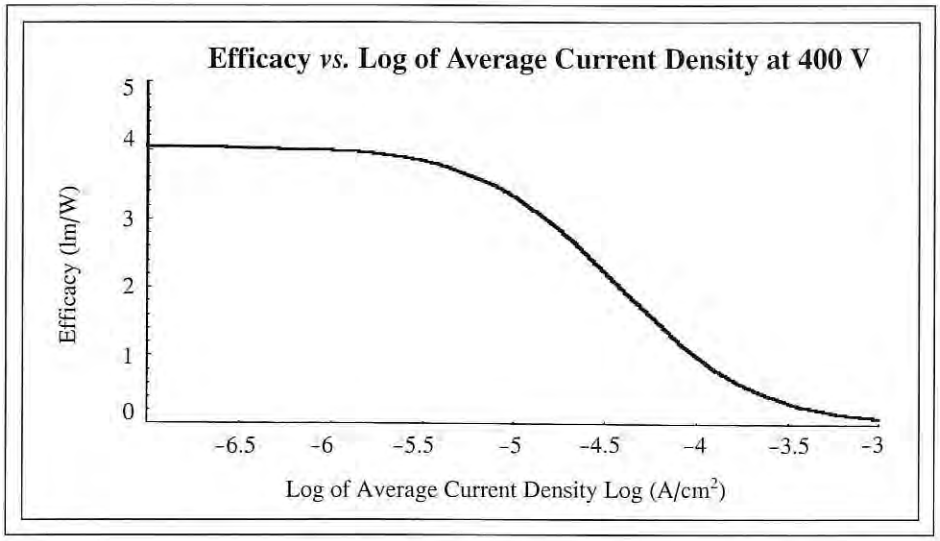

***Fig 2:** Calculated plot of the efficacy (lm/W)* vs. *log of the average current density (A/cm^2) for a green ZnCdS:Cu,Al phosphor operating at 400 V with a 2-μsec pulse width. The duty factor is 1/1440 and the peak current can be found by multiplying by 1440.*

coating of MgO, which has a high secondary emission, has been used in place of aluminum.

Why are aluminum or MgO coatings beneficial? Electrons striking the phosphor cause charge to accumulate on the surface. As the accelerating voltage increases, more electrons accumulate and act as a potential barrier to the excitation of the phosphor. The light output no longer increases with increasing accelerating voltage. This "sticking voltage" is typically between 5 and 8 kV, but it depends on the phosphor. A few atomic layers of MgO with a high secondary electron emission works well up to 15 kV, but it has been shown to be unreliable at higher voltages over the lifetime of the phosphor.

An aluminum layer will stop low-energy electrons and increase the threshold voltage at which light emission occurs - typically from 300 V with no aluminum layer to 3 kV - depending on the thickness of the aluminum layer. The aluminum layer prevents charging and thereby increases light output for accelerating voltages up to 60 kV. It also reflects light out that would otherwise be lost to the inside of the CRT.

Aluminization also protects against ion burn on the phosphor due to negative ions striking the phosphor. Aluminization will also increase phosphor lifetime by preventing contaminant gases from reacting with the phosphor. The drawback is that the tube designer must supply an accelerating voltage roughly 4 kV greater than would be required to produce the same light if the phosphor were not coated with aluminum.[2]

Should FED phosphors have an aluminum layer? One FED manufacturer is already using an aluminum layer for a flat-panel display that operates between 6 and 10 kV. The aluminum layer would obviously not be needed if the display were operating below 4 kV. Why did the manufacturer choose to operate at higher voltages?

Operating Voltage and Light Output

To operate phosphors at low voltages is inefficient because these phosphors become efficient at higher voltages. CRT manufacturers have long known that phosphors operate most efficiently and live longest at high voltages. (The exception is ZnO:Zn green phosphor, which operates most efficiently at 800–1000 V, but it is easily surpassed in efficiency by other phosphors operating at high voltages.)

CRT makers are generally happy with high-voltage phosphors. The desire for low-voltage red and blue phosphors came from FED manufacturers making color triode displays. The displays were arcing and had current-leakage problems along the spacers separating the anode and cathode at high voltage. Lower voltages would mean no arcs and smaller leakage currents. Switching the device on and off was done with 10–20 V on the gate.

The calculations that tell us that it is not efficient to operate phosphors at low voltages were performed years ago by knowledgeable phosphor researchers, but they were not well understood by display designers, who were not part of the phosphor community. The display designers hoped that materials developers would provide new color phosphors or that existing phosphors that were highly efficient at low voltages would be discovered and prove the experts wrong.

At the time, there was not a lot of phosphor efficiency data at low voltages - and no way

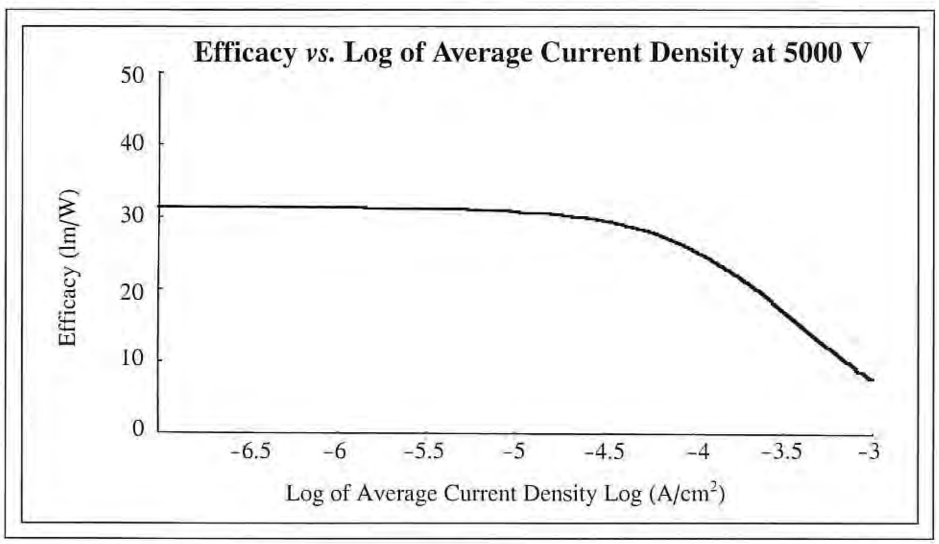

***Fig. 3:** Calculated plot of the efficacy (lm/W)* vs. *log of the average current density (A/cm^2) for a green ZnCdS:Cu,Al phosphor operating at 5000 V with a 2-μsec pulse width. The duty factor is 1/1440 and the peak current can be found by multiplying by 1440.*

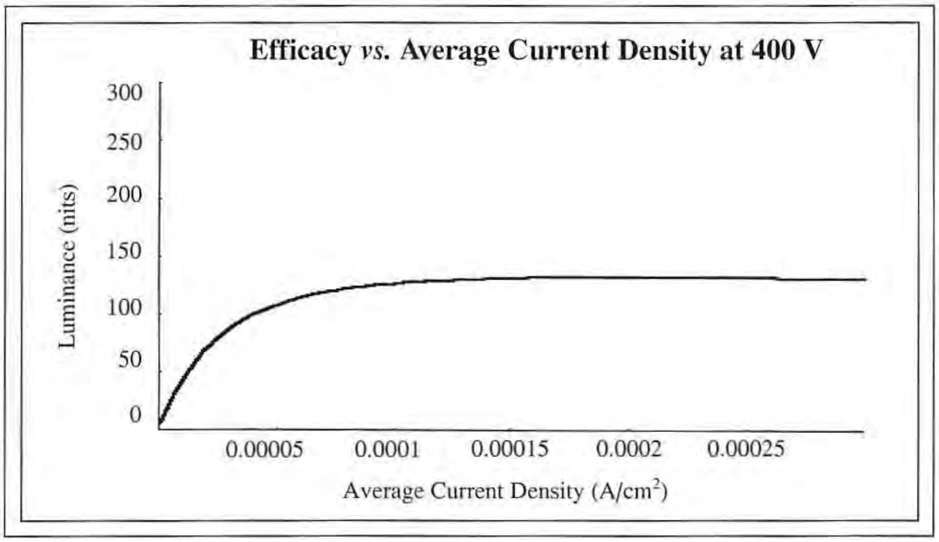

***Fig.4:** Calculated plot of the luminance (nits)* vs. *average current density (A/cm^2) for a green ZnCdS:Cu,Al phosphor operating at 400 V with a 2-μsec pulse width. The duty factor is 1/1440 and the peak current can be found by multiplying by 1440.*

of predicting what the efficiency of a high-voltage phosphor would be at low voltages and high current densities without measuring every phosphor. If one doesn't measure the phosphor in this regime, how can a prediction be made about its luminance when the operating current density is so large that the phosphor is in saturation? And the phosphor data that did exist showed that phosphors which were operated at low voltages needed to be run at high current levels or in saturation to produce acceptable light output.

A quick review will show where the problem lies. A VGA display operating at 60 Hz has a refresh time of 16.7 msec. The standard duty factor (df) for three colors is $1/(3 \times 480)$, or 0.000694. If a smaller pulse width (2 μsec) and larger refresh rate (f = 140 Hz) could be achieved, the phosphor would operate more efficiently.

We want to achieve 200 nits. The current density J is usually calculated from the simple equation $J = 3.1415 \times 10^{-4} L)/(\eta V)$, where J is the current density in A/cm^2, L is the luminance in nits, η is the efficiency in lm/W, and V is the anode voltage. A plot of the efficiency *vs.* voltage of a green phosphor, ZnCdS:Al,Cu, with no aluminum layer, shows an efficiency of 32 lm/W at 5000 V.[3]

The simple equation shown above indicates that the required average current density is 0.39 $\mu A/cm^2$. Dividing by the df 0.000694 indicates that the peak current needed is 565 $\mu A/cm^2$. At an even lower anode voltage, 400 V, the efficiency would be 4 lm/W. The calculation shows the average current density is 39 $\mu A/cm^2$, and the calculated peak current density is 56.5 mA/cm^2. The current density is 100 times greater at 400 V than at 5000 V! The true peak current density must be even larger because the true efficiency is lower since the current density indicates that the phosphor is in saturation.

This example demonstrates two points. Low-voltage phosphors require high peak current densities and the efficiency, η, is a function of voltage and current and must be accounted for by a different equation.

The phosphor efficiency and luminance is better described by the equations below:

$$\eta = \frac{(V-V_0)^n}{10,000V}\left[\frac{\pi \cdot f}{1+g\left(\frac{J^{\gamma_1}}{(V-V_0)^{\gamma_2}}\right)}\right] \text{(lm/W)} \quad (1)$$

$$Lv = f(V-V_0)^n\left[\frac{J}{1+g\left(\frac{J^{\gamma_1}}{(V-V_0)^{\gamma_2}}\right)}\right] \text{(nits)} \quad (2)$$

These equations can be used to model any phosphor, with or without aluminum. The efficacy η and luminance Lv can be predicted for any voltage V or average current density J within the data points. This cannot be done with the simple equation shown previously.

To demonstrate the utility of these equations, we fitted them with values from the data in Ref. 3 (Table 1). We estimated the current density at which saturation occurs, and we assumed that efficiencies, which increase at short pulse (2 μsec), and high current density are related to efficiencies at long pulse and low current conditions for some phosphors.[4] A plot of the computed efficiency versus voltage at 1-$\mu A/cm^2$ continuous current using Eq. (1) is shown in Fig. 1. A plot of the computed efficiency *vs.* average current density at a df of 0.000694 using Eq. (1) at 400 and 5000 V is shown in Figs. 2 and 3.

Using our VGA example, let's find out what the complex equations predict the average current would be at 400 and 5000 V for a green display using unaluminized green ZnCdS:Cu,Al to produce a luminance of 200 nits. The value for average current density at 5000 V predicted by the simple equation is pretty close to the value 0.39 $\mu A/cm^2$ shown in Fig. 3 using Eq. (2). The value for average current density at 400 V to achieve 200 nits is never realized; the closest value is 140 nits at 160 $\mu A/cm^2$ predicted by Eq. (2) and shown in Fig. 4. This is 4.1 times greater than the 39 μA predicted by the simple equation, which does not account for current saturation.

Phosphor Lifetime

The average current density is about 410 times greater at 400 V than at 5000 V for a display operating a green ZnCdS:Cu,Al phosphor with no aluminum layer. This means 410 times more electrons per second must be deposited at 400 V than at 5000 V to get the same light output. What does this mean for phosphor lifetime?

According to Pfahnl's law, the lifetime of a phosphor is related to the total deposited charge per area - the "Q dose." The lifetime is defined as the time it takes the light output to decrease to one-half of its initial value. The Q dose for a CRT phosphor is typically 100 C/cm^2, and projection-TV phosphors have even larger Q doses. More recent work shows that the energy, or accelerating voltage, of these electrons is also important.[5] Electrons deposited at higher voltages do less damage than do those at lower voltages because their penetration is deeper, the volume is greater, and the energy deposited per volume is less, causing less damage. Phosphors operating at high voltages live longer than those operating at low voltages.

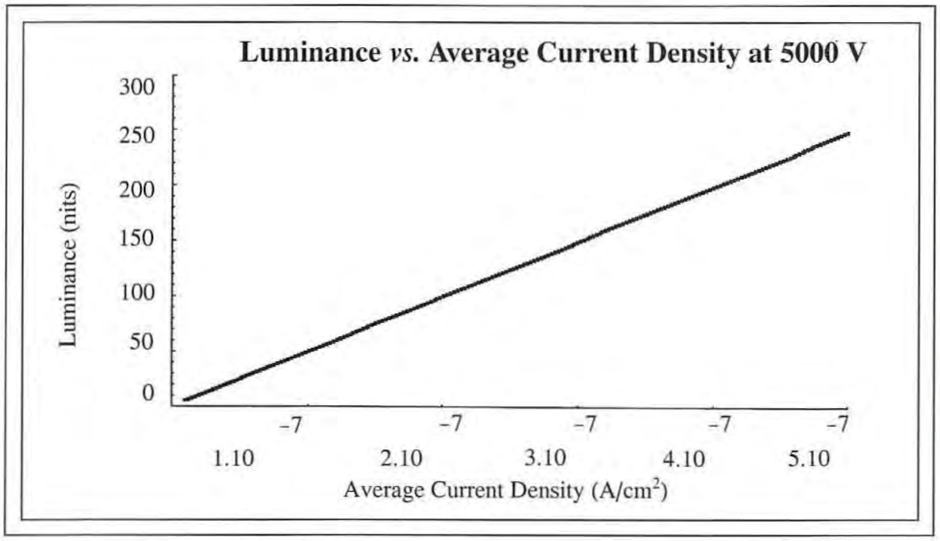

Fig. 5: *Calculated plot of the luminance (nits)* vs. *average current density (A/cm^2) for a green ZnCdS:Cu,Al phosphor operating at 5000 V with a 2-μsec pulse width. The duty factor is 1/1440 and the average current can be found by multiplying by 1440.*

Experimental results show that the effect is even more profound for unaluminized ZnS phosphors, which show shorter lifetimes than expected for phosphors operating at low voltage. The lifetime of an unaluminized ZnS phosphor can be as short as $Q = 10$ C/cm^2 at 5 kV.[5] (Aluminized ZnS phosphors and unaluminized oxide phosphors are much longer lived.)

The simple approximate equation that converts these dose numbers to hours is given by $t = QV\eta/1.131L$, where t is the lifetime in hours, Q is the number of C/cm^2 to half intensity, V is the phosphor voltage, η is the efficiency in lm/W, and L is the luminance in nits. Assuming that the efficiency of ZnCdS:Cu,Al is similar to ZnS:Cu, then the lifetime for an unaluminized ZnS:Cu phosphor operating at 140 nits at 5000 V, $\eta = 32$ lm/W, in a VGA display is over 7000 hours. For the VGA unaluminized ZnS:Cu phosphor operating at 140 nits at 400 V, when $\eta = 0.7$ lm/W and $Q = 5$ C/cm^2, the lifetime would be about 8.8 hours. From this example, it can be seen that a phosphor with both a large Q and η operating at a voltage as large as possible would be the best choice.

Table 1

Phosphor	Green (ZnCdS:Cu,Al)
Growth exponent	$\eta = 1.60$
Threshold voltage	$V_0 = 119$ V
Conversion constant	$f = 625$ nits-cm^2/A
Reciprocal saturation voltage, current density	$g = 2.08 \times 10^7$
Current saturation exponent	$\gamma_I = 1.144$
Voltage saturation exponent	$\gamma_2 = 0.9206$
Duty factor	df = 0.000694

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Taiwan's Growing FPD Industry

With support from Japan and claims of indifference from Korea, Taiwan is adding substantially to the world's 14- and 15-in. AMLCD capacity – and is working on PDPs.

by Julie Mei-Ling Chen and Ken Werner

EARLY IN THIS DECADE, a shortage of laptop LCD panels from Japan - then the only supplier nation - temporarily crippled Taiwan's laptop-computer business. The vision of hundreds of thousands of otherwise complete Taiwanese laptops waiting for displays had a lasting effect on Taiwan's computer-industry executives, who were convinced that Japan's laptop manufacturers were receiving preferential treatment from display suppliers that were often divisions of the same company. "Never again," said Taiwan's high-tech executives. "Never again."

The commitment to create a domestic source of supply for Taiwan's notebook displays was a serious one, but the shortage of the early '90s was followed by periods of oversupply, format changes, and plummeting prices - good times to be a buyer of LCDs, bad times to become a manufacturer.

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The Stars Align

As the decade matured, several factors realigned themselves - and all of them encouraged Taiwan's electronics industries to invest heavily in AMLCD manufacturing. First, Taiwan had become a global force in computer hardware. Its 1998 computer-hardware production of $19.25 billion was bettered only by the U.S. and Japan. More to the point, Taiwan shipped 6 million notebook computers in 1998 worth $8.42 billion and

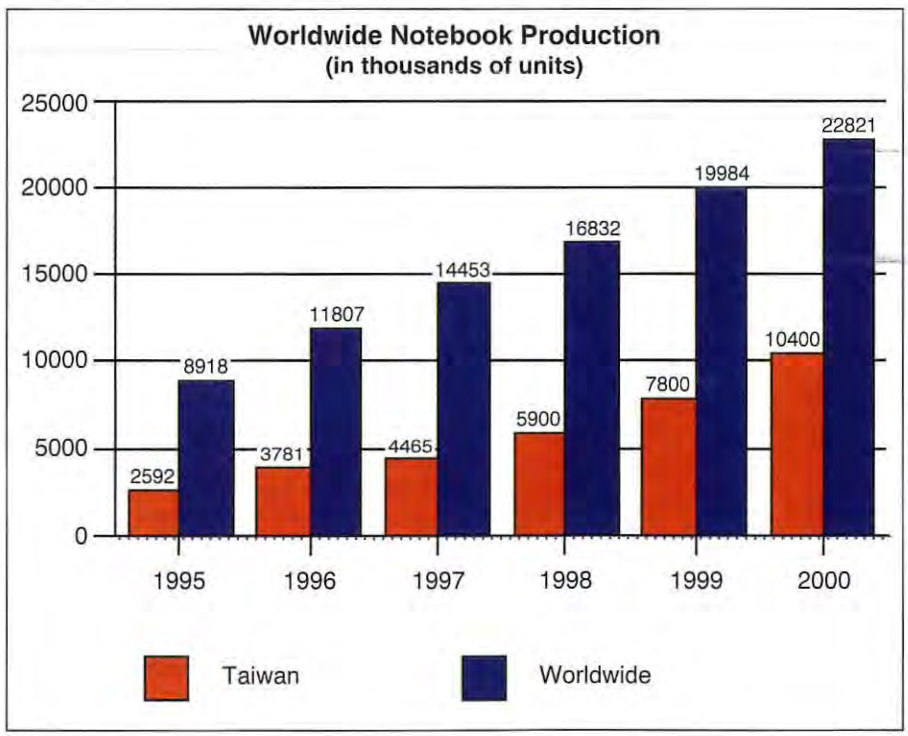

Fig. 1: Taiwanese manufacturers will produce nearly half of the world's notebook computers in 2000. (Data: MIC)

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3 million LCD monitors (Fig. 1). Clearly, if Taiwan's computer and monitor makers want to buy AMLCDs from Taiwanese suppliers, those suppliers would have a more-than-adequate market.

But wasn't 1998 a ridiculous time to consider building AMLCD plants? There was an oversupply of AMLCDs, manufacturers were awash in red ink, and prices were in free-fall. In fact, it turned out to be a brilliant time to build if the marketing pundits, who turned out to be right, were to be believed. Although their numbers differed, several major market-research organizations agreed that the brutal oversupply of 1998 would become a shortage in 1999 and 2000.

In addition, it looked like a refreshing predictability was about to make itself felt in the area of notebook display sizes and formats, with the dominant size going from 12.1 in. in 1998 to 13.3 in. in 1999 and 2000, and to 14.1 in. in 2001, but with significant sales for both 13.3 and 14.1 in. throughout the period.

But there was even more to make 1998 an exciting year for Taiwan's developing AMLCD industry. While Korea and Japan had suffered severely from Asia's financial crisis, Taiwan, with its relatively small companies carrying low indebtedness, went comparatively unscathed. There was money to invest thanks to Taiwan's very strong capital market, and investors could get good deals on equipment and technology alliances from troubled Japanese companies. In addition, some Japanese and Korean companies seemed to be coming to the conclusion that 14- and 15-in. AMLCDs would soon be commodities with too small a margin to make at home. Early this year, when one of us (KIW) asked Jun H. Souk, V.P. of Samsung Electronics, if he was worried about Taiwan's AMLCD industry, he said that Taiwan would not be a competitive concern for a couple of years. "Then they'll be doing small sizes (12–13 in.), and Samsung will be doing larger displays (17–18 in.)."

Many of the Taiwanese companies making new fabs have Japanese technology partners, who see Taiwan as a good source of high-quality displays at reduced cost. Chungwha's deal with Mitsubishi involved the transfer of Mitsubishi's display-manufacturing technology to Chungwha, and allows Mitsubishi to buy 30% of Chungwha's production of 14- and 15-in. displays.

The investment involved is huge. During 1999, no less than five major new AMLCD fabs were being constructed in Taiwan at an average cost of $600 million each – a total of $3 billion. The investment has produced sweeping changes in related industries, suppliers, and customers, and has created a shortage of display and manufacturing engineers.

Who Are the Players?

Taiwan's six major AMLCD players are Prime View International, Unipac, Chi Mei, Acer Display, HannStar, and Chunghwa (Table 1).

Prime View International. Current product lines are color TFT-LCD modules from 1.8 to 6.4 in.; and 6.4-in. VGA, 9.2-in. SVGA, and 10.4-in. SVGA color TFT-LCD modules. Plans are to dedicate Fab 1 for small-to-medium-sized TFT-LCD production; capture major market shares in automotive, consumer A/V, and mini-notebooks in 1999 through the company's strong worldwide sales network; and to continue to offer limited samples of 13.8-in. TFT-LCDs, with plans to produce larger sizes in Fab 2. Prime View International's parent company is YFY, a leader in paper manufacturing, biotech research, banking, and software development.

Unipac Optoelectronics. Current product lines are color TFT-LCD modules from 4 to 6.8 in. Plans are to continue partnerships with PixTech for FED manufacturing, Kopin for miniature-display manufacturing, and Matsushita for developing Gen 3.5 manufacturing technology and setting up a new line for 600 × 720-mm targeted for mass production in November 1999. New products will be 13.3 and 14.1 in. for notebooks and 17 in. for monitors. Parent company UMC is the second largest semiconductor enterprise in Taiwan.

Chi Mei Optoelectronics. Chi Mei is a newcomer to the TFT-LCD industry. Two companies were formed in 1997: Chi Mei Electronics Corp. for color-filter manufacturing and Chi Mei Optoelectronics Corp. for TFT-LCD manufacturing. In December 1998, Chi Mei Electronics announced its first prototype color filter (for STN) and began offering samples to local LCD manufacturers. Chi Mei Optoelectronics is setting up a Gen 3.5 fab scheduled to begin mass production in Q4 '99 with a Phase 1 capacity of 30k/month, expanding to 85k/month in 2001. Parent company Chi Mei Enterprises is the world's largest manufacturer of ABS polymer, and is famous for its art museum in Tainan.

Acer Display Technology. Although its parent company, The Acer Group, is a major force in computers and related technologies, Acer Display is a newcomer to the TFT-LCD industry. The company signed a technology-transfer agreement with IBM in March 1998, and it was planning to start producing 13.3-in. TFT-LCDs on its 600 × 720-mm line in July 1999 with an initial capacity of 5k/month, ramping up to 30k/month in 2000, when it also plans to reach the break-even point and go public.

HannStar Display Technology. A newcomer to the TFT-LCD industry, HannStar is partnering with Toshiba for the transfer of the Japanese company's 550 × 650-mm TFT-LCD technology. Parent company Winbond is Taiwan's third-ranking semiconductor company.

Chunghwa Picture Tubes (CPT). CPT is the world's largest supplier of color data tubes, but is a newcomer to the TFT-LCD industry. It has partnered with Mitsubishi/ADI to transfer the technology for its 550 × 670-mm manufacturing line. Production of

Table 1: Taiwan's TFT-LCD Players

Company	Founded	Glass Size	Capacity	AMLCD Mass Production Started	Technology
Prime View	1992	370 × 470	36k/month	Q4 '96	Own
Unipac	1992	300 × 400	30k/month	Q4 '99	Matsushita
Chi Mei	1997	620 × 750	30k/month	Q4 '99	Own
Acer Display	1997	600 × 720	20k/month	Q3 '99	IBM
HannStar	1997	550 × 650	30k/month	Q1 '00	Toshiba
Chunghwa	1997 (TFT)	550 × 670	20k/month	Q2 '99	Mitsubishi

14- and 15-in. displays began in May. Parent company Tatung is a leading manufacturer of TVs, monitors, and appliances.

Although they are not yet building TFT-LCD fabs, Taiwan companies Picvue, URT, and Wintek are substantial manufacturers of TN- and STN-LCD modules. The three companies together produce 7.4% of the world's TN- and STN-LCD modules.

The Road Ahead

Taiwanese companies are intentionally carving out a piece of the FPD business that involves high volumes and low margins. Taiwanese high-technology executives point to their previous success with other high-volume low-margin high-quality high-technology products such as desktop and notebook computers, scanners, CD-ROM decks, and semiconductors.

The Taiwanese business style is "bottom-line sensitive." Successful managers have mastered the art of cost control. They are pragmatic, flexible, and trained to have a great sense of urgency.

Japan is currently providing materials and know-how, but Taiwanese executives are confident that they can develop their own expertise and fill in the gaps in the local supply chain. And Taiwan has a supply of very low-cost labor in Mainland China, where Taiwanese-owned plants are built regularly. The Taiwanese display industry also plans to source materials from the mainland, thus cutting costs further – as well as further cutting the ties that bind it to Japan. ■

conference report

Recent Display Developments and Products in Russia

April's EuroMonitor event showed that although Russia and the Commonwealth of Independent States are not known for large-scale manufacturing of displays, they provide remarkably fertile ground for display research and development.

by Viktor V. Belyaev

THOSE INTERESTED IN advances in display technology - from cathode-ray tubes (CRTs) and plasma panels to organic light-emitting diodes (OLEDs) and field-emitter displays (FEDs) - might want to schedule a trip to Moscow next spring. The EuroMonitor International Exhibition-Fair and Conference has been held there for the past 3 years, and the April 1999 session featured a wide range of interesting prototype and manufactured devices.

The exhibition and conference is organized by the Russian National Association DisplaySoyuz and the Russian SID Chapter, and enjoys the participation of many different institutions and companies throughout Russia and the Commonwealth of Independent States (CIS). With so much attention focused on display research and development in other parts of the world, this event provides an excellent opportunity to connect with a rich source of new technology and facilities that might otherwise be overlooked.

For example, Russia now has the facilities and technology required for any type of optical lens in plastic or glass. The glass production can be particularly efficient, making low-volume production profitable even in quantities of 50–100 arrays per year. Russia also has everything needed to undertake development and fabrication of active-matrix liquid-crystal-display (AMLCD) projectors.

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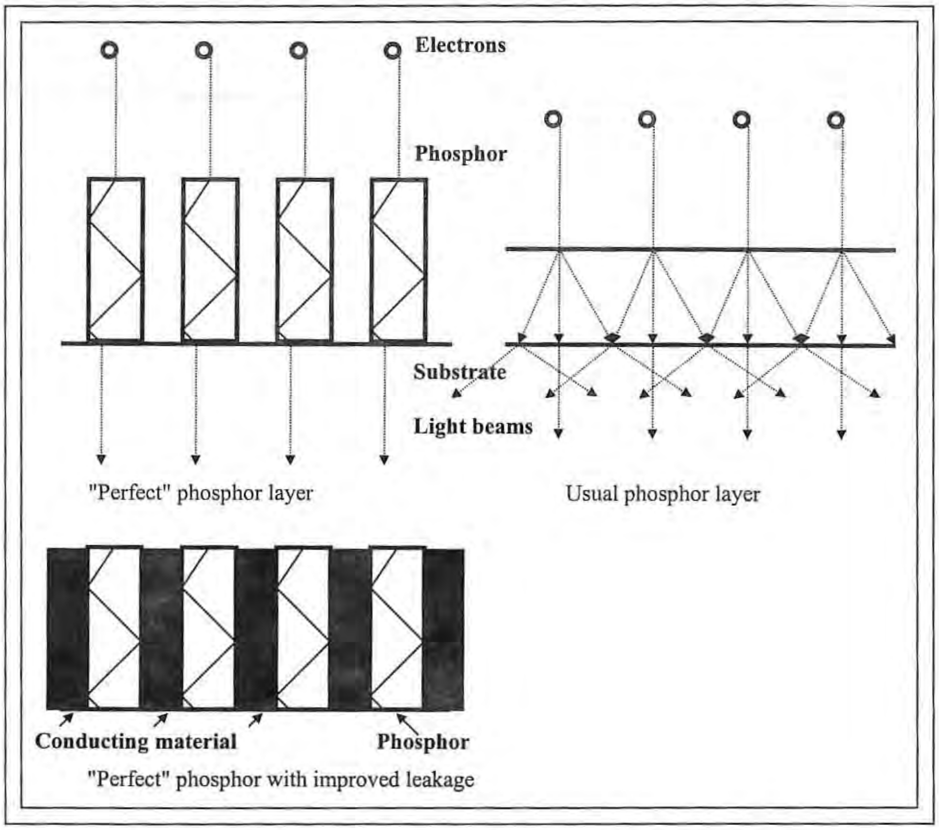

Fig. 1: At EuroMonitor '99, Prof. E. I. Givargizov compared his "perfect" phosphor layer with a typical phosphor layer and a "perfect" phosphor with improved leakage.

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One special feature of EuroMonitor '99 was sponsored by the Scientific Industrial Company Concept Engineering, which made it possible for institutions and firms without any funding to display their advanced developments. The Institute of Electronics (Minsk, Belarus) took advantage of this opportunity to show a new color LED panel controlled by a light beam, and R&D PRES (Moscow) exhibited new software simulating various electro-optic effects in liquid crystals.

An overview of the highlights from the exhibition and conference clearly demonstrates that a lot of interesting research is taking place in Russia and the CIS countries.

Projection Technology

R&D Institute Platan (Moscow Region) and ARTI Co. (Moscow) have developed a CRT projector with increased light flux (~5000 lm) and resolution (~2000 TV lines). Platan has had promising results with multi-beam excitation of phosphors, with up to eight electron beams at a time in the lab. Controlling the raster scans has proven to be a sophisticated problem, and to date only a two-beam design is ready for commercial production. This produces twice the light flux (~250 lm) of single-beam designs.

OAO VNIIIS (Institute of Light Sources) and Saransk and Rosich Co. (now ARTI Co.) of Moscow have created a joint venture to create metal-halogen lamps for projectors. These lamps range from 150 to 1000 W.

Laser CRTs offer great promise for large displays, up to 100 m^2. A new version aimed at the home market creates a 2-m image with up to 3000 pixels/line.

FEDs

Researchers have made advances in FED technology, and a number of developments on FED microtips and phosphors were presented.

Prof. E. I. Givargizov, Institute of Crystallography, Russian Academy of Sciences (RAS), Moscow, described a new structure of a "perfect" phosphor for FEDs. Small crystals of ZnO or CdS phosphor as large as 3–5 mm and as high as 10 mm are grown on the substrate to reduce light scattering and increase the light efficiency of the screen. An electron emitted from the cathode generates a light beam in a crystal grain that does not scatter, but instead propagates within a narrow range after a few reflections inside the crystal. Gaps between crystal grains can be filled with a conducting material to increase contrast and reduce charge leakage (Fig. 1).

The report by Prof. A. T. Rakhimov, R&D Institute of Nuclear Physics, Moscow State University, created a lot of interest when he displayed data on the emission of cold-cathode films fabricated on a base of carbon compounds. The luminance of the film is at least one order of magnitude higher than those made with other known technologies. A prototype of a display with matrix driving has been made.

Good samples of FEDs were fabricated at the R&D Institute Volga (Saratov, Russia), where three types of devices with autoemission cathodes were developed. Of particular interest was a variation using edge emission.

Vacuum Fluorescent Displays

The R&D Institute Volga also demonstrated ultra-bright and large VFD panels. This technology is expected to make possible

- Jumbo tiled VFD screens as large as 50–100 m^2 and with a brightness up to 5000 cd/m^2.
- Prototypes of monochrome and multicolor 8- and 14-in. VFD TV sets.
- QVGA and VGA monitors with 35-V operating voltages.

Plasma-Display Panels

MicS Co. (Moscow) demonstrated a big screen made up of 20 × 20-cm ACPDP modules, which rapidly became the hit of the exhibition. This design can produce a bright picture – 400 cd/m^2 with a 3-mm pixel or 1000 cd/m^2 with a 6-mm pixel in peak mode – over a large screen area with high resolution. The panels are only 10 cm thick, and optics can correct edge effects between tiled modules. The ac plasma panels used in the display were from NPO Plasma (Ryazan', Russia).

OLEDs

Dr. E. I. Mal'tsev, the Frumkin Institute of Electrochemistry, RAS, Moscow, reported on mechanisms of luminance and electron-hole transport in organic phosphors. A set of new aromatic polyimides with luminance in various spectral ranges, high light efficiency, and approximately equal magnitudes of electron and hole mobility was developed at the Institute. Unusual systems, such as nanocrystalline J-aggregates, were synthesized to obtain emission in the red and infrared spectral ranges.

LEDs

Optonika, a subsidiary of Pulsar (Moscow), presented different bi- and tri-color LED-panel modules designed for traffic lights. Hewlett-Packard is now the firm's main partner for supplying components.

A report by Prof. Y. V. Trofimov, Institute of Electronics, National Academy of Sciences (Minsk, Belarus), described the latest in traffic security systems. LED and LCD panels received a lot of attention, but relatively old technologies, such as blinking lights and mechanical semaphores, are also regarded as effective. A combination of technologies may be the most effective strategy.

Prof. Trofimov also reported on a new type of optoelectronic device that can act as both a photoreceptor and an LED. The devices have extremely steep dependence of emission intensity on intensity of a controlled light beam. An LED panel was demonstrated with an arbitrary image that was written with a laser pointer. The image, or a portion of it, can be erased with a green beam. A demonstration display with colored segments was also shown. All the colors shown – milk-white, red, green, blue, and yellow – were approximately of the same intensity.

Electrochromic Materials

Different organic electrochromic materials were developed recently at the Frumkin Institute of Electrochemistry (Moscow) and R&D Institute of Fine Chemical Synthesis (Dolgoprudnyi, Moscow Region). They are used in controlled light filters, displays, and panels with slow information change (response time less than 1 sec). The advantages of electrochromic devices are low current density (mA/cm^2), low power consumption (mW/cm^2), thermal stability, and low cost.

V. F. Ivanov from the Frumkin Institute of Electrochemistry presented results obtained in polyanilines. In comparison with inorganic materials, the polymeric ones have a greater electrochromic effect: 200–300 instead of 60–80 cm^2/Coulomb.

LCD Technology

R&D Institute Volga demonstrated fast-switching light modulators. These would be suitable for eye protection in welding masks, volume vision systems, transmission-mode LC panels with very high contrast, and monochrome 14-in. VGA panels for teaching computers.

Dr. V. Volodin of the Stock Co. NPP RusPE (Moscow) has developed and patented addressing methods that promise to reduce or eliminate spurious effects on LC passive panels. The drivers based on these methods can significantly improve picture quality, gray scale, color accuracy, and homogeneity of high-speed passive SVGA or TV LCDs up to 20 or 22 in. on the diagonal. The addressing methods can be three times faster than traditional techniques. Working jointly with Volga, Saratov intends to create high-speed STN panels for TV applications based on the approach.

A. Kalashnikov of the Moscow State Technical University of Radiotechnics, Electronics, and Automation, and Prof. V. V. Belyaev of the Central R&D Institute Cometa (Moscow) presented a new method to create the active element of an AMLCD. The processes depends on materials whose capacitance has a non-linear dependence on voltage, such as another liquid-crystal layer or ferroelectric liquid crystal. The twist-effect voltage-transmission performance was increased by about 20 times. The addition of a ferroelectric liquid-crystal layer can also help maintain a written image and thus increase its contrast.

Liquid-crystal photoalignment processes were discussed in the report by Dr. V. M. Kozenkov from R&D PRES (Moscow). He described the control of the surface tilt angle in the 0–90° range. Photochromic materials have yielded promising results in this process. They have high stability when subjected to light and different spectra for polarization. The induced birefringence can be as high as 0.35. An image written in this medium can be kept for 10 years or more. These substances also have high thermal stability – up to polymer melting temperatures of about 160°C.

Other new types of liquid-crystal alignment were reported by GNIIKHTEOS (Moscow), using silicon organic compounds with increased heat, frost, and chemical stability; and Moscow Lomonosov University, using plastic substrates with controlled relief. Physical properties of silicon organic films were considered for 20 classes of substances.

Visual Perception, Standards, and Certification

Dr. A. S. Blokhin, Head of the Program Electronic Cinema at the R&D Institute of Materials for Movies and Television (Moscow), presented a very simple and efficient approach for watching three-dimensional pictures while using a single raster image. Any projection unit can be made with a unit that eliminates ocular convergence. Two equal pictures with orthogonal polarization are formed on a special screen. A viewer uses simple polarizing glasses, and the brain's innate ability to combine the two images creates the three-dimensional effect. As both images are projected simultaneously, it appears that there is no fatigue effect for the viewer. Coupled with surround sound, the effect could be striking.

Prof. I. I. Litvak, from the Moscow State Technical University of Mathematics and Electronics and the firm Elita, presented a strategy to optimize alphabets for character displays. To reduce power consumption, this approach does not turn off all portions of a character, but instead leaves on a basic symbol that contains the maximum number of repeating elements in the character set. To test this, characters were analyzed for different configurations – such as 5×7 and 7×9 pixel cells – and the alphabet was divided into different groups based on different basic symbols. These symbols were tested, and then improved based on the rate of false recognitions. The final set of symbols resulted in only one-tenth as many mistakes in recognition.

Prof. G. G. Demirchoglyan from the Russian Physical Culture and Sports R&D Institute (Moscow) considered different systems of eye protection for PC users. He proposed special glasses to reduce operator fatigue.

Virtual-reality applications were the subject of two reports from the Institute of Philosophy of RAS (Moscow). Dr. N. N. Nosov discussed how to determine which applications are best suited to virtual-reality systems, based on the modeling of important psychological factors. Human behavior in critical circumstances must work in harmony with the display system; a pilot and an aircraft are different systems, and the pilot's display requirements are different when flying alone from when flying in formation. To be effective, the system design must include the human as an element in the whole system.

Prof. V. M. Rubin presented a system for the semiotic classification of virtual-reality systems. The first type is "imitation reality," and resembles familiar reality; this is one of the least-advanced areas in the field. "Conditional reality" imitates just the perceived spatial features of an environment. "Projective reality" or "artificial reality" is based on an idea or a concept that may not have any analog in actual reality. Virtual reality can also imitate sensations other than sight, which Rubin classifies as "border reality." For example, some modern surgical procedures take place in a multi-layered space.

If a picture is worth a thousand words, then a trip to EuroMonitor in Moscow can give one a far better picture of the state of display technology research and development in Russia and the CIS than might any article. There are new technologies and opportunities for partnering and joint ventures, making the future look bright for displays from this part of the world. ■

SID *Conference Calendar*

Next Show!

The Sixth International Display Workshops (IDW '99)

The 6th International Display Workshop (IDW '99) will be held at the Sendai International Center in Sendai, Japan, December 1–3, 1999. This year's workshop is comprised of 265 papers and will feature Poster Sessions, Author Interviews, and Exhibits. The workshops should be of interest not only to researchers and engineers, but also to those who manage companies and institutions in the display community.

1 DECEMBER 99

6th International Display Workshop (IDW '99)

SENDAI, JAPAN
DECEMBER 1–3, 1999

- Scientific and technological advances in information displays will be presented in ten workshops on:
  - LC Sciences & Technologies – AMLCDs
  - Passive-Matrix LCDs – FPD Materials and components – CRTs – Plasma Displays
  - ELs, LEDs, & Phosphors – FEDs – Large Area & Projection Displays – 3-D Technologies & Human Factors

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
  - Product Exhibits – Display Technology Showcase

25 SEPTEMBER 00

20th International Display Research Conference (IDRC '00)

PALM BEACH, FLORIDA
SEPTEMBER 25–28, 2000

- 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

14 NOVEMBER 00

8th Color Imaging Conference: Color Science, Engineering, Systems & Applications

SCOTTSDALE, ARIZONA
NOVEMBER 14–17, 2000

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

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continued from page 4

Since for such a company there is no real value based on sales and profits, its value can only be based on the *perception* of the investors. The more the investors can be convinced of "future potential," the more the value is likely to increase. Press releases, technology demonstrations, and alliances with respectable companies become the tools in this process of perception-building. A campaign of announcements hinting at the latest breakthrough technologies, development contracts awarded, discussions with respected large corporations, influxes of new investment dollars, mention of publications in well-known journals, patents awarded, and participation in industry associations all become tools for the publicity campaign. Never mind that there are no sales, that product announcements are repeatedly rescheduled or modified, and that money is being burned at an ever-increasing rate. Think of the future potential. Believe. Buy that stock now while you can still get in before it "really takes off."

Is there anything here that is fundamentally different from betting on horses at the track? Is there anything different from gambling at the tables in Las Vegas or Monte Carlo? Yes, there is. In those situations you know the odds. In buying stock in these highly promoted new-technology ventures, you don't.

As I cheerfully answered my ringing telephone, the voice on the other end began, "Dr. Silzars, we haven't met before, but a friend recently showed me your column and I was wondering if you could answer a few brief questions." "Of course, how can I be of help?"

"Well, you see, recently I bought some stock in 'Symbiotically Incredible Display Technologies' and I was wondering what you think of their technology? Do you think they will be introducing their product as they have announced, and do you think their stock is going to skyrocket once their product hits the market?" Uh-oh, I was afraid that we were heading down this path.

Later that day, another call came in. "Dr. Silzars, I am a broker with a firm that I'm sure you know. I have been talking to the management at Symbiotically Incredible Displays and they are really on to something. Even though I'm not a technologist, I can tell you that this is going to be the greatest technology since the integrated circuit was invented. Why don't you guys at *Information Display* do a better job of writing about these new technologies? The stock in this company would go up even faster and my investors would benefit if you would just tell the world what this company has created. And, by the way, why don't you jump in and buy some of this stock for yourself. You've got to know how this technology is going to take off any day now."

Experience is a great teacher. These phone calls no longer leave me wondering what to say. My response is polite and well-practiced. However, one thing that I will never understand is why the calls always come *after* the investment has been made and not before. Nevertheless, here is what follows.

"I'm so glad you called, but please let me explain that the price of the stock in this company or any other has little do with the technology they are touting. The price of the stock is dependent only on the *perceptions* of other investors like you. What I think of the technology and whether it has any merit are completely beside the point. Someday that will become an important issue when a real product finally needs to be introduced, but I can't tell you when that someday is any more than I can tell you when you will live happily ever after. I can tell you for sure that companies can go for many years on the perception of a breakthrough technology about to happen. So please don't ask me for my opinion because it is of no consequence."

"But, Dr. Silzars, don't you think that this is one of the greatest developments in display technology? Couldn't you just give me your opinion?" Oh yes, I could, and do I ever have an opinion! But my response continues, "Your stock purchase decision should only be based on what you believe other investors think of this company. You will of course want to be prudent to watch for changes in their product announcements, but as you well know, the investment community currently responds to influences other than product sales or profitability. You will need to watch those to evaluate your investment decision."

And to my new-found stockbroker friend, I add the following, "*Information Display Magazine* will be pleased to report on this new technology as soon as the management of this company is willing to tell us the specifics of how these products function. If we can understand what it is that they are claiming, we will be the first to give them all the exposure they merit. However, we will not make announcements about displays that are claimed to work on some mysterious new principle, especially when the company is unwilling to let us examine a working prototype. And, by the way, I never make investments in technology companies I track. The reason is that understanding a technology has no relationship to the price of the stock. Also, being able to predict the eventual course that a company will be forced to take is of even less help in projecting what the stock will do in the interim before everyone else figures out the inevitable. In buying and selling stock, real knowledge can be a major detriment. And to date I have not been able to figure out how to compensate for that or to ignore it altogether. So it is best for me not to invest in those companies that I know too much about. However, thank you for your call. I will discuss this matter with Ken Werner, our Editor-in-Chief, and we will take another look at this company to see if we can write anything constructive about their new display technology."

Is it any surprise that all too frequently this investment world, built on perception and make-believe, collides with our technical world, where eventually the promises must be fulfilled and the products demonstrated?

Finally, there is the "minor" issue of manufacturing these marvelous new products for a price that consumers are willing to pay. When is the last time that you heard an investor ask about manufacturing cost and volume production? As companies have learned over and over again, those may not be the glamorous tasks, but they just happen to be the boundary condition between success and failure of the enterprise as a real (profitable) business.

Investment and cost-effective manufacturing – can you think of two other topics of more interest for additional discussion? Therefore, I look forward to hearing your opinions on both. You can reach me by e-mail at silzars@attglobal.net, by phone at 425/557-8850, by fax at 425/557-8983, and by regular mail at 22513 S.E. 47th Place, Issaquah, WA 98029. ■

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