DISPLAY-MANUFACTURING ISSUE

Information DISPLAY

November 2000
Vol. 16, No. 11

SID

Official Monthly Publication of the Society for Information Display

UXGA e-Book Demonstration at IDMC

- **Alien Engineers a Ramp-Up**
- **LCD Yield-Management Software**
- **25 Years of SID in Japan**
- **IDMC 2000 Report**

Information DISPLAY

NOVEMBER 2000
VOL. 16, NO. 11

COVER: At IDMC, Samsung Electronics showed this impressive 6.6-in. UXGA TFT-LCD in an e-Book mock-up. The display, which is a technology demonstrator, has a pixel density of 302.4 ppi, luminance of 340 cd/m², CR of 200:1, and optical response time of 40 msec at 25°C, and uses a two-channel LVDS interface. This is an e-Book display on which one wouldn't mind reading The Brothers Karamazov. *Find out more in our exclusive IDMC coverage beginning on page 30.*

Ken Werner

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
- Plasma Displays for HDTV
- LEP Displays
- Protecting Intellectual Property
- The Best of 2000

INFORMATION DISPLAY (ISSN 0362-0972) is published eleven times a year for the Society for Information Display by Palisades Institute for Research Services, Inc., 411 Lafayette Street, 2nd Floor, New York, NY 10003; Leonard H. Klein, President and CEO. EDITORIAL AND BUSINESS OFFICES: Jay Morreale, Managing Editor, Palisades Institute for Research Services, Inc., 411 Lafayette Street, 2nd Floor, New York, NY 10003; telephone 212/460-9700. Send manuscripts to the attention of the Editor, ID. Director of Sales: Michele Klein, Palisades Institute for Research Services, Inc., 411 Lafayette Street, 2nd Floor, New York, NY 10003; 212/460-9700. SID HEADQUARTERS, for correspondence on subscriptions and membership: Society for Information Display, 31 East Julian Street, San Jose, CA 95112; telephone 408/977-1013, fax -1531. SUBSCRIPTIONS: Information Display is distributed without charge to those qualified and to SID members as a benefit of membership (annual dues $75.00). Subscriptions to others: U.S. & Canada: $36.00 one year, $7.50 single copy; elsewhere: $72.00 one year, $7.50 single copy. PRINTED by Sheridan Printing Company, Alpha, NJ 08865. Third-class postage paid at Easton, PA. PERMISSIONS: Abstracting is permitted with credit to the source. Libraries are permitted to photocopy beyond the limits of the U.S. copyright law for private use of patrons, providing a fee of $2.00 per article is paid to the Copyright Clearance Center, 21 Congress Street, Salem, MA 01970 (reference serial code 0362-0972/00/$1.00 + $0.00). Instructors are permitted to photocopy isolated articles for noncommercial classroom use without fee. This permission does not apply to any special reports or lists published in this magazine. For other copying, reprint or republication permission, write to Society for Information Display, 31 East Julian Street, San Jose, CA 95112.

editorial

"Into Manufacturing, Joe"

SID President Aris Silzars is fond of saying that all revolutionary advances in display technology depend on breakthroughs in materials. Of course, true "revolutions" occur infrequently, despite our overuse of the word. Significant advances in display technology and applications also stem from breakthroughs in processes, packaging, driving schemes, and the philosophical exercise known as "system partitioning" – and these fortunately occur with much greater frequency than revolutions. But regardless of its source, many a genuine innovation in display technology has foundered on the rocks that line the channel seductively named "Into Manufacturing."

It does have a nice macho ring to it: "That design looks good, Joe. Send it into manufacturing!" But the channel to successful manufacturing is treacherous. Currently being pounded on the rocks is the appealing FED technology based on Spindt cathodes. Carefully developed in laboratories for over 30 years and successful in low-volume pilot production, the technology is now struggling to make it through the channel into volume manufacturing. When Motorola and others tried to ramp up production, they found that subtle contamination inside the display deprived it of the lifetime needed for a consumer product. Now, Candescent feels it has the problems licked. But the world does not stand still. If Spindt-tip FEDs make it through the channel, they may well have company from carbon-nanotube- and planar-emitter FEDs.

Plasma displays have made it through the channel to manufacturing, but not without some serious scraping against the rocks. Although the major manufacturers are making very nice displays, they have been disappointed in their efforts to bring manufacturing costs down as quickly as they had intended. As a result, PDPs are far from being the mass-market products their makers had expected them to be by now. (But Korean and Taiwanese makers are promising to cut costs and prices soon.)

CRTs, on the other hand, defying many predictions of their imminent demise, still hold on to more than half the global display market, thanks in large part to vast automated production lines that crank out millions of high-quality tubes at remarkably low cost – and do so as effortlessly, it seems, as Hershey cranks out chocolate bars.

So what's the point? Making one or five or ten displays in a lab is an art. But just as there are no atheists in foxholes, there can be no artists on production lines. When a display goes into production, it must go with a set of instructions that always work. Materials and processes must be well characterized, and the same inputs must always produce the same output: working displays with predictable specifications.

The production line is such a vastly different environment from the development lab that it's no wonder transitions from the latter to the former are often rocky. And that's why we devote each November's issue of *ID* to manufacturing issues. We can barely scratch the surface in a few articles, but we can at least address some manufacturing matters and remind ourselves that saying, "Send it to manufacturing, Joe" is likely to be the easiest part of the process.

continued on page 48

Information DISPLAY

a view from the hilltop

It Wouldn't Converge ...

In my junior year of college, I took a class taught by a mathematics professor who was most likely a brilliant theoretician. Unfortunately, that brilliance did not translate into his abilities as a teacher. To this day, I remember him as the worst teacher in all my years of formal education. As it quickly became apparent, not only had he selected a text that was beyond the capabilities of everyone in the class, but with each passing day he convincingly demonstrated his own lack of ability to explain the material.

The culmination of this miserable year was the last few weeks that we spent trying to learn how to prove that certain mathematical series, in their limit, either converged or diverged. Now these were not the more familiar series that I later found useful in my graduate engineering education. These were the kind that only a dedicated mathematician could love. No matter what theorems I tried to apply, I couldn't seem to come up with conclusive answers. On the final written examination, I covered the pages mostly with good intentions and was fortunate to escape the class with a mediocre but passing grade.

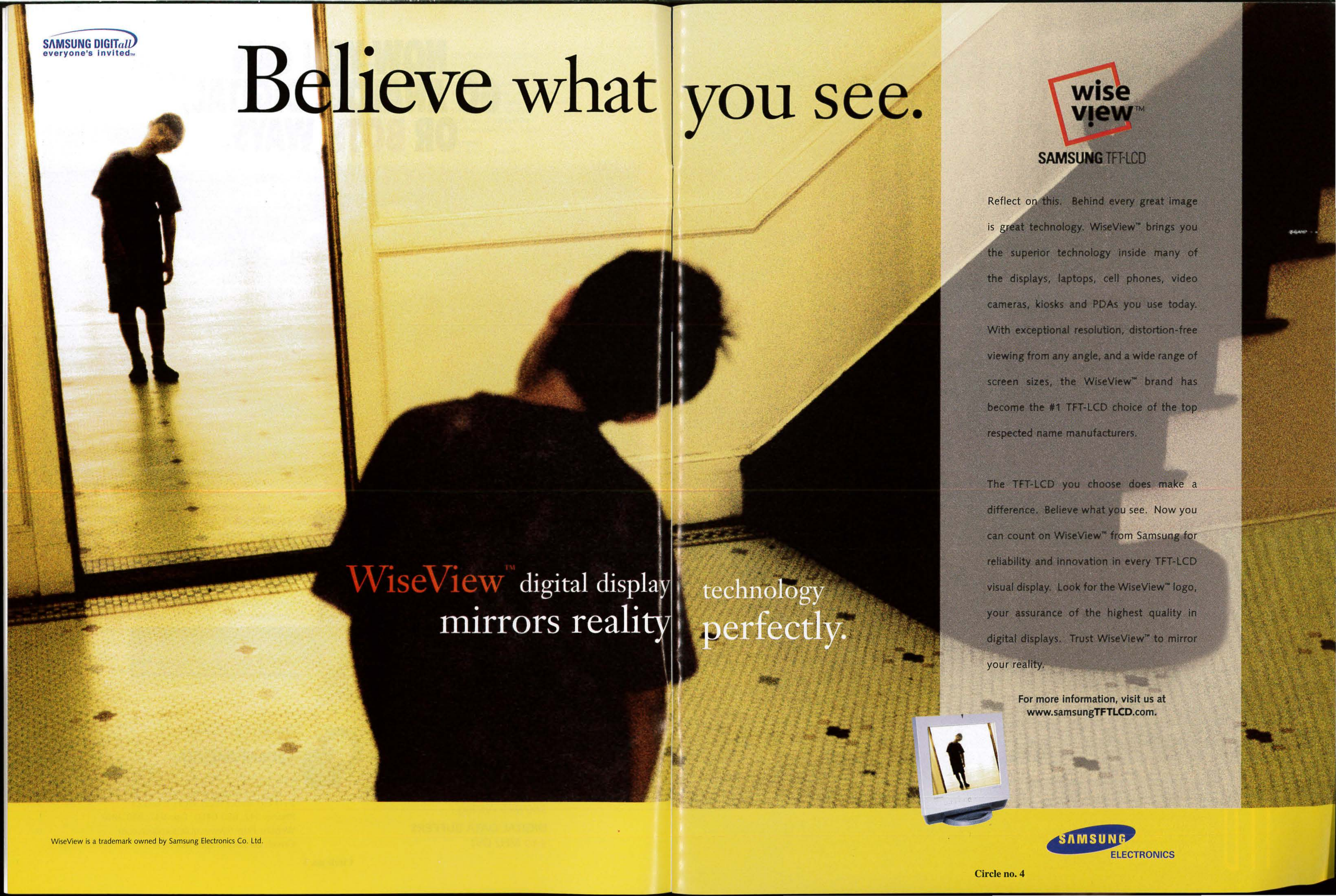
The memory of this experience is so strong that whenever I hear someone talk about convergence or divergence, I am immediately transported back to this intensely frustrating and frankly miserable time. Given this, I'm sure you won't be surprised if I tell you that I have a strong reaction whenever I hear or read about the "convergence" of computers and television, or the Internet and television. And never having succeeded at proving which of those mathematical series converged or diverged, I continue in my quest to arrive at an answer. Perhaps, if I can't do those weird math series, at least I can propose an answer to the convergence or divergence of electronic media.

For this analysis, I believe that I have "nature" on my side. And it seems that nature likes diversity (*i.e.*, divergence) rather than combinations of dissimilar things (*i.e.*, convergence). Therefore, by inference we can perhaps show that we too are more likely to appreciate divergence than convergence. The examples are numerous. In nature, we proliferate species rather than have two different ones come together. Of course, some go extinct, but then others evolve to take their place. We don't have too many cats and dogs getting together to make catdogs. Bluebirds and robins pretty well keep to their own kind. Botanists and breeders sometimes work for years to create combinations that will make plants more disease resistant or animals that have superior capabilities. Even then the result is usually a new subspecies rather than a convergence of two distinctly different plant or animal types.

Are we too far afield in using biological processes as examples for a discussion of technological convergence or divergence? After all, it does not require a procreation process to create a new Web TV or Internet appliance. But a look at some popular attempts to combine technological functions seems to lead us to the same conclusion already arrived at by "mother nature." For example, the many attempts to combine cars and airplanes or cars and boats have only resulted in vehicles that performed both functions poorly. Their value was more in their novelty than in their functionality. Similar results have been demonstrated time and again in trying to combine appliances such washers and dryers,

continued on page 42

Society for Information Display
31 East Julian Street
San Jose, CA 95112
408/977-1013, fax -1531
e-mail: office@sid.org
http://www.sid.org


SAMSUNG DIGITall
everyone's invited™
Believe what you see.
wise view™
SAMSUNG TFT-LCD
Reflect on this. Behind every great image is great technology. WiseView™ brings you the superior technology inside many of the displays, laptops, cell phones, video cameras, kiosks and PDAs you use today. With exceptional resolution, distortion-free viewing from any angle, and a wide range of screen sizes, the WiseView™ brand has become the #1 TFT-LCD choice of the top respected name manufacturers.
The TFT-LCD you choose does make a difference. Believe what you see. Now you can count on WiseView™ from Samsung for reliability and innovation in every TFT-LCD visual display. Look for the WiseView™ logo, your assurance of the highest quality in digital displays. Trust WiseView™ to mirror your reality.
For more information, visit us at www.samsungTFTLCD.com.
WiseView™ digital display technology
mirrors reality perfectly.
WiseView is a trademark owned by Samsung Electronics Co. Ltd.
SAMSUNG ELECTRONICS
Circle no. 4

Flat Display Measurement

Westar's FPD Performance Measurement Systems give you something unique -- precision and flexibility. Westar's FPM Systems provide photometric and colorimetric measurements, real-time reporting of test results, increased test and analysis productivity, and performs standard tests as well as your own custom tests.

Westar's FPD Performance Measurement System

- Tests displays up to 54" automatically.
- Tests for luminance, chrominance, contrast & viewing angle performance...and more!
- Uses popular sensors, such as PR, Minolta, and Topcon.

Performs VESA, TCO '99 and ISO 13406-2 tests!

Powerful ViewPoint™ software integrates sensors, motion control, analysis, and reporting functions. It also includes a wide variety of fully integrated display interfaces!

FREE Video and CD

For more information on Westar's revolutionary new systems, call today for our **FREE** video and CD.

Westar

Products for better displays.™

USA:	Westar Corporation, 636-498-6004 ext.286
Japan:	Kyokuto Boeki Kaisha, Ltd., 03-3244-3795
Korea:	Truco, Inc., 02-3465-2004
Taiwan:	Advanced Team Enterprise Co., Ltd., 02-27035466
China:	Advanced Team Technology Service, 769-632-6399
Europe:	Ginsbury Electronics, Ltd., +44 (0) 1634-298900

www.westar.com/fpm

Circle no. 6

Circle no. 7

Circle no. 8

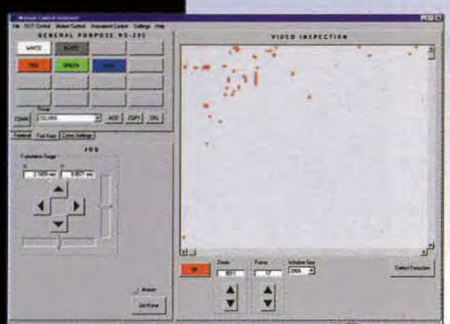
Microdisplay Inspection

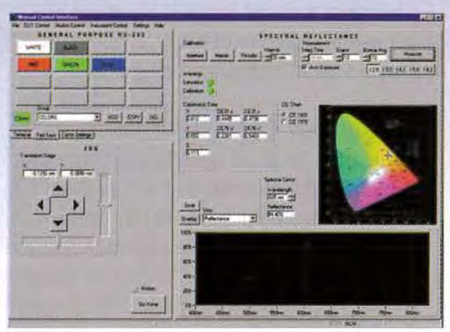
The Westar Microdisplay Inspection System tests microdisplays with resolutions QVGA to beyond UXGA, without changing camera or optics!

For laboratory, production, or QA/QC environments, the new Microdisplay Inspection System makes fast and accurate measurements using an integrated optical assembly with computer-controlled zoom and focus, spectrometer instrument, and a CCD camera.

Perform standard tests, including:

- % reflectance
- contrast ratio
- uniformity
- pixel defects
- spectral response
- plus others!





Powerful MicroPoint™ Software has two modes: Manual Control Interface for rapid laboratory measurements, and an Automated Test Sequencer for production.

Call today for more information!

WESTAR

Products for better displays.™

USA:	Westar Corporation, 636-498-6004 ext.286
Japan:	Kyokuto Boeki Kaisha, Ltd., 03-3244-3795
Korea:	Truco, Inc., 02-3465-2004
Taiwan:	Advanced Team Enterprise Co., Ltd., 02-27035466
China:	Advanced Team Technology Service, 769-632-6399
Europe:	Ginsbury Electronics, Ltd., +44 (0) 1634-298900

www.westar.com/mdis

Circle no. 9

Bringing Alien Technology Down to Earth

Having demonstrated that its innovative packaging technology works in laboratory quantities, the company with the strange name is thinking hard about how to engineer a glitch-free ramp-up.

by Stan Drobac and Glenn Gengel

FLUIDIC SELF-ASSEMBLY (FSA) technology was introduced to the display community in the November 1999 issue of *Information Display Magazine*.[1] A novel approach to integrating electronics into display backplanes, FSA promises to facilitate the production of inexpensive displays on plastic using roll-to-roll manufacturing techniques. However, the journey from interesting technology to production process can be a long one, and often proves fatal to the travelers. The team at Alien Technology, having experienced a few such journeys in previous assignments, is working to realize the potential of FSA with a minimal amount of risk. Here is Alien's approach to moving FSA into production, and a report on the progress being made.

Technology Overview

In the FSA process, specifically shaped semiconductor devices ranging in size from 10 μm to several hundred micrometers are suspended in liquid and flowed over a surface that has correspondingly shaped "holes" or receptors into which the devices settle. The shapes of the devices and the holes are designed so that the devices fall easily into place and are self-aligning. Alien has demonstrated the self-assembly of thousands of such devices in a single process step (Fig. 1).

***Stan Drobac** is Vice President of Business Development at Alien Technology Corp., 18410 Butterfield Blvd., #150, Morgan Hill, CA 95037; telephone 408/782-3977, fax 408/782-3910, e-mail: sdrobac@alientechnology.com. **Glenn Gengel** is Vice President of Manufacturing at Alien.*

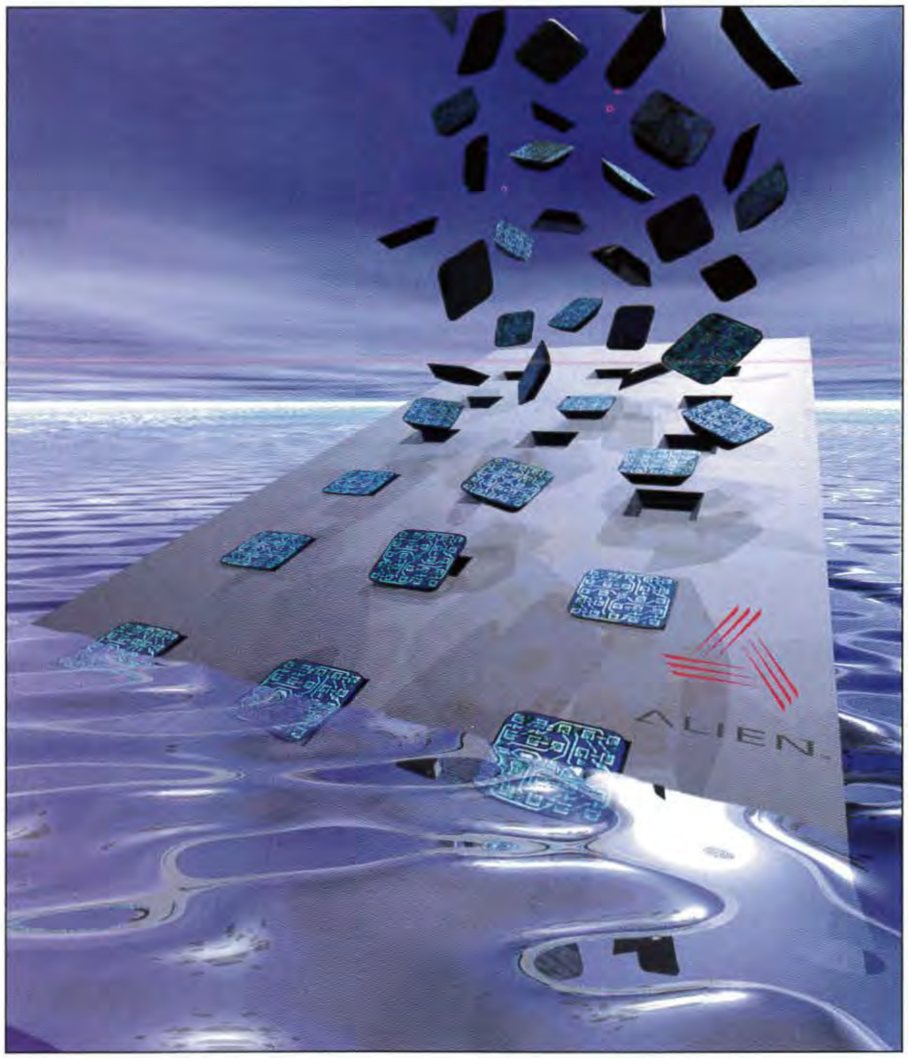


***Fig. 1:** This artist's rendering of the Fluidic Self-Assembly (FSA) process shows NanoBlock™ ICs falling into formed holes embossed in a substrate.*

0362-0972/00/1611-012$1.00 + .00 © SID 2000

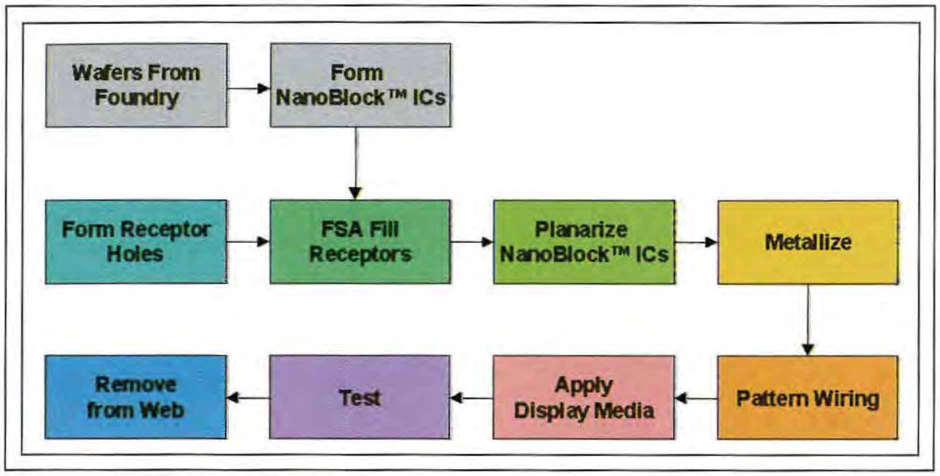
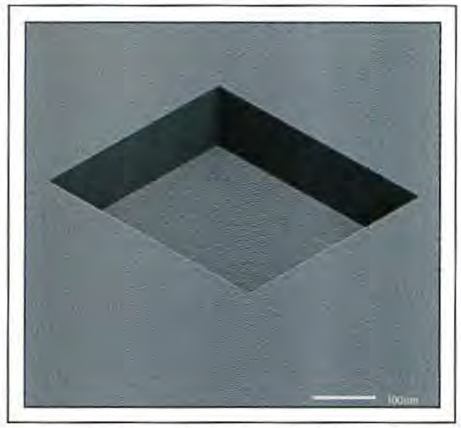


Fig. 2: As indicated in this top-level flow chart of the FSA-based display-manufacturing process, many of the processes are familiar and use standard equipment.



Stimsonite

Fig. 3: Shown is an unretouched scanning-electron-microscope (SEM) photograph of a NanoBlock IC receptor hole formed in a flexible plastic-film substrate made by Stimsonite, a subsidiary of Avery Dennison and a merchant producer of optical films.

The FSA process uses single-crystal-silicon NanoBlock™ ICs fabricated on standard silicon wafers in industry-standard CMOS wafer foundries. The use of submicron IC technology allows the incorporation of substantial intelligence within the display, including control and memory at each pixel, along with optimized drive voltages or currents. Alien's first products, for example, will implement a serial architecture – a four-wire connection to the display – with about 100 local transistors supporting each pixel.

Because there are no high-temperature transistor-processing steps, flexible plastic substrates can be used, making roll-to-roll "web" manufacturing practical. Alien's production will be on a web line, which promises to be much more productive and cost much less than the sheet-glass lines typically used in display production. This is a very untraditional approach. Will it really work?

Alien has shown that NanoBlock chips can be assembled using FSA, interconnected, and mated to electro-optic media to form working displays. Still, it is appropriate to question whether – and how, and how quickly – the technology can be developed to a production-ready state. After all, it's not just an incremental improvement to existing TFT-LCD technology. FSA involves unique new equipment and processes without a production history.

Also, although it is easy to grasp the concept of shaped chips falling into matching holes, it is not clear that the statistical odds of getting a hole filled are high enough to build complex displays. A mainstream notebook-computer display, or even a third-generation mobile-phone display, could require over a million thin-film transistors (TFTs) in an active matrix. That might translate to hundreds of thousands of NanoBlock chips that need to be deposited without a single empty hole if the display is to work – quite a yield challenge. On top of that, a small company, not one of the industry giants, is doing the technology development.

Risk-Reduction Strategies

To maximize the probability of success, Alien has adopted a few basic strategies that guide its business decisions and its manufacturing approach. The first is to start production with the simplest possible displays and add complexity incrementally. In much the same way that the current LCD industry started with cal-

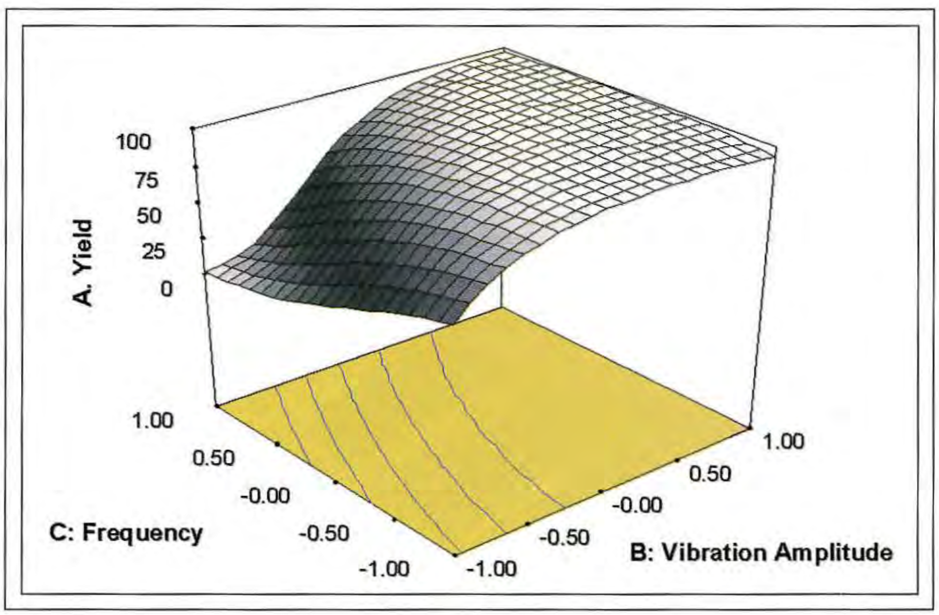
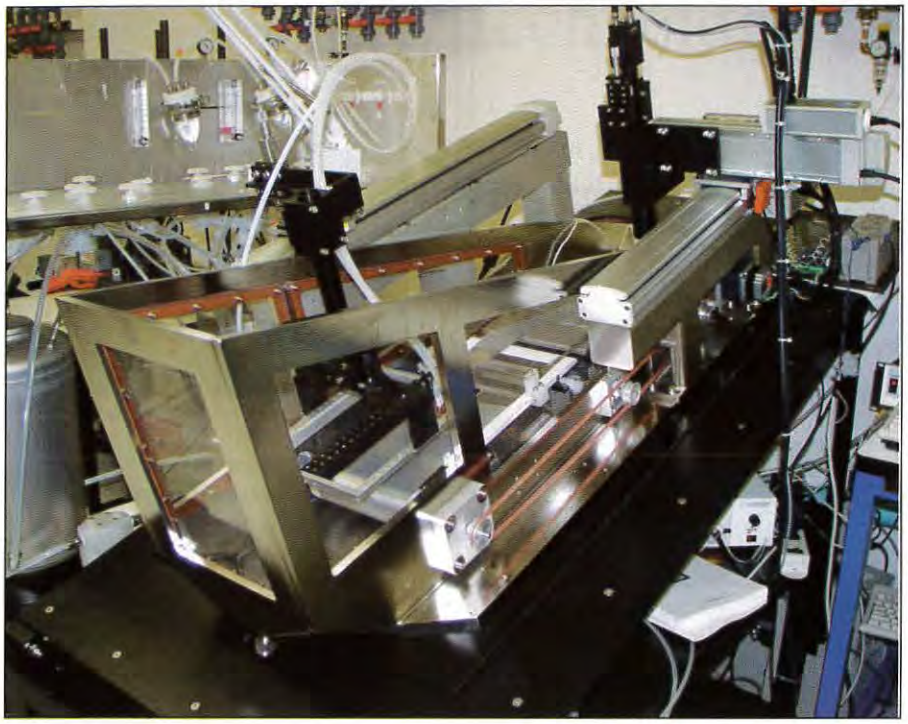
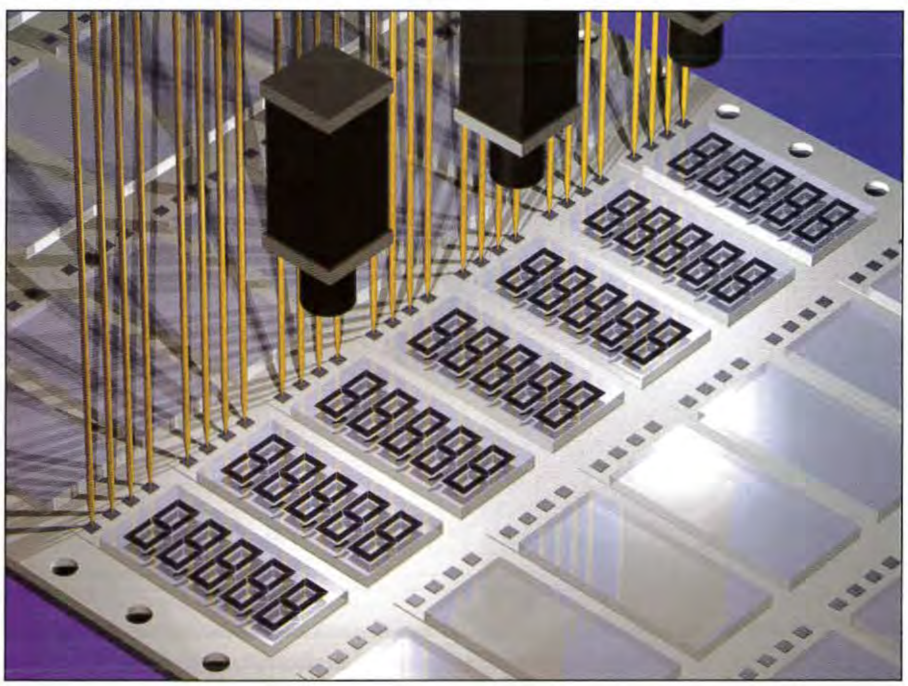


Fig. 4: The FSA process offers many degrees of freedom and has shown itself to have wide process windows with respect to the important variables. In this example, a response-surface map shows FSA fill yield as a function of substrate vibration frequency and amplitude.



Alien Technology

Fig. 5: A fourth-generation automated FSA machine equipped for both moving substrates and moving dispenser heads has been developed.



culator displays long before growing into TFT color notebook-computer screens, Alien will first build five-digit seven-segment displays for electronic-purse smart cards. Product complexity will grow rapidly from there, but will always be a step or two behind what process capability can support.

The second key strategy is to avoid inventing anything that can be borrowed from another company or industry. Although the FSA process step (dropping chips into holes) is new, nearly all of the other processes in the manufacturing flow are identical to those used for making high-density flexible circuits, particularly the tape-automated-bonding (TAB) tape used widely for attaching driver chips to conventional LCDs. Alien has brought on-staff a number of web-processing experts with experience in the volume manufacturing of such circuits, and has engaged with Toray Engineering, which is widely acknowledged as the leading equipment manufacturer and factory architect in the field. Toray is working closely with Alien in process definition and development, materials selection, equipment design, and factory planning.

Related to the borrow-from-others philosophy is a focus on establishing mature engineering and production disciplines from the beginning. Statistical characterization and process control, and the establishment of an ISO-compatible infrastructure, are being emphasized in the development work. Although the company is a year away from beginning volume production, Alien's engineering and manufacturing staffs has already been through a series of multi-day courses on statistical techniques. To minimize regulatory risk – and be a good corporate citizen – Alien's production facility is being designed to near-zero discharge specifications.

Finally, Alien recognized that a small – about 70 people in July 2000 – company may be nimble, but it can move its technology forward faster if it engages intelligently with industry leaders that have complementary resources to contribute. So in addition to the engagement with Toray Engineering, Alien

Fig. 6: *Early Alien displays will have approximately 100 transistors per pixel, allowing the displays to be organized as a single shift register. This will allow displays to be tested on the web as they are driven in actual use – with only four connections: power, ground, clock, and data.*

Alien Technology

Fig. 7: A display in smart-card format, made with NanoBlock ICs placed by FSA into flexible plastic film, interconnected with deposited aluminum, and driving a 20-V PDLC film laminated onto the backplane is shown at the left. Red, green, and blue polymer-LED displays made from Dow Chemical material and driven by NanoBlock chips are shown at the right.

has struck deals with major players in the display and materials fields for joint development and potential production relationships.

Process Development – What's Really New?

Actually, the proper question is "What *has to be* new?" In the spirit of using off-the-shelf equipment, materials, and techniques wherever possible, Alien has evaluated the process flow with an eye toward acquiring anything available from the outside and focusing development resources on things that are truly unique to the FSA process. The top-level process flow for making displays using FSA is shown in Fig. 2; discussion of each of the major steps follows.

Production of NanoBlock™ ICs. Alien Technology buys NanoBlock chips in wafer form from merchant IC foundries using off-the-shelf (typically CMOS) processes. The Alien-specific processing begins with wafer thinning and polishing, followed by a mask and etch process to form and separate individual blocks. The thinning and polishing reduces the wafer to a thickness of about 100 μm, and is handled by outside contractors who routinely do such wafer thinning for IC makers and users.

The mask and etch process is distinguished from routine semiconductor practice only in that it is performed on the back of the wafer. This requires a somewhat unusual mask alignment through the silicon to features on the front of the wafer, but can be accomplished by an infrared alignment option available for standard IC lithography equipment. The etch, a wet KOH etch commonly used in IC fabs, follows the silicon crystal planes and gives the chips their characteristic 54.7° beveled sidewall with 100% repeatability.

Although the resulting NanoBlock chips are interesting and unusual in appearance, their production is accomplished without any fundamentally new processes. Alien's development activities in this area are focused on characterization, process control, and simplification.

Substrate Preparation (Receptor-Hole Formation). The concept of a receptor hole is new – and is indeed unique to FSA. Because Alien will be working with plastic film, we will need a high-productivity embossing machine capable of stamping holes, and such a machine could be developed fairly easily in concert with Toray. But the technology for making embossed plastic film with the required precision in volume already exists and is available from manufacturers who make, for example, patterned optical films. Such films are produced in volume with nanometer tolerances. Alien is currently working with two potential suppliers of such film and has verified that the required capabilities are in place (Fig. 3).

Still, there is substantial engineering work under way in selecting the base material to be used. The requirements include standard-product availability; dimensional stability, including the ability to hold the shape of the embossed holes; and compatibility with anticipated process temperatures (up to 150°C) and chemical exposures. Several acceptable candidates have been identified, and evaluations are under way to select one for initial production.

Fluidic Self-Assembly (FSA). This is both the core process of the Alien approach to manufacturing and the one area requiring truly original process and equipment development. Although FSA has been in development since 1994, Alien is still dedicating roughly 50% of its development staff to the process. The process continues to be the subject of countless experiments and exercises in data collection (Fig. 4).

Fortunately, the FSA process offers many degrees of freedom and has proven to have wide process windows with respect to the important variables. Among the variables that have been evaluated and mapped are the characteristics and composition of the fluid (viscosity, additives to prevent NanoBlock chips from clumping together, bonding agents to glue the chips to the receptor holes, *etc.*), substrate tilt and speed relative to the dispenser head, vibration, and the optimum ratio of NanoBlock chips dispensed to the number of holes needing to be filled.

Alien Technology

Fig. 8: *In May 2000, Alien opened its new pilot R&D facility in Morgan Hill, California, with the company's trademark otherworldly trappings.*

The need to accommodate NanoBlock chips of different sizes adds to the workload; it is important for Alien to understand how optimum process conditions vary with chip size. The range of usable sizes does not appear to be an issue – chips from 50 μm square to about 2 mm square have been assembled without difficulty, and there has been no indication of any limits being approached at either end of that range. Work is now under way to determine the best way to support multiple block types in a single substrate.

There has also been much effort in designing the equipment to be used for FSA. The original laboratory configuration used NanoBlock chips dispensed manually from pipettes for both initial fill and for selective fill of empty holes. Alien has developed its fourth-generation FSA machine (Fig. 5), with automated electronic controls and valveless NanoBlock chip handling that can transport chips without the risk of damage posed by closing valves.

Planarization and Metallization. There is very little new in these steps; they use off-the-shelf materials, standard TAB tape manufacturing equipment, and conventional process recipes. The planarization layer is a photo-definable polymer that serves as a dielectric and provides a smooth topology for the subsequent conductive layer. The conductors will initially be patterned aluminum, with an option to use indium-tin-oxide (ITO) or conductive polymers if appropriate.

Optical Media Application/"Cell Assembly." The second development focus (after the FSA process) is the selection and application of the electro-optic material to be applied to Alien's electronic backplane. The use of single-crystal silicon for the NanoBlock chips leads to something of an embarrassment of riches, in that virtually any material can be driven in an optimal manner. Because drive capability has not narrowed the options, Alien continues to experiment with several different media types, including polymer-dispersed liquid crystal (PDLC), electrophoretics, organic and polymer light-emitting diodes (OLEDs/PLEDs), and various types of liquid or gel-form LC materials. It is likely that Alien will ultimately produce displays with several of those media types, but the selection for initial production has not been made at the time of this writing.

For materials that can be obtained in solid form, such as PDLC, the "assembly" process will be a simple lamination, with one contact to be made from the active backplane to a single top ITO electrode. For materials requiring fill-and-seal operations, techniques will be borrowed from existing LCD-industry practice.

Testing. Alien's unique display architecture makes testing a fairly simple task, at least for the company's first few generations of product. The NanoBlock chips will have on the order of 100 transistors per pixel, allowing each display to be organized as a single shift register, with local control and static memory at each pixel. A display will thus need only four connections (power, ground, clock, and data) and can easily be driven directly on the web through simple probe contacts (Fig. 6). Charge-coupled-device (CCD) cameras will check the display output, comparing it to a stored reference image.

Status

When last year's *Information Display* article was written, Alien had successfully concluded a proof-of-concept stage. NanoBlock chips could be placed into embossed holes on plastic film by FSA, interconnected with deposited aluminum, and used to drive a simple display. However, the NanoBlock chips had no intelligence and limited drive capability, so the demonstration looked nothing like a real product and actually consisted of surface-mounted LEDs attached to the backplane with a conductive epoxy.

Alien has since produced working, fully processed PDLC displays on plastic film that approximate the construction of the first-production smart-card display (Fig. 7). In addition, substantial experience has been gained in patterning and driving various types of PDLC, cholesteric-LC, and polymer-LED media.

The first intelligent NanoBlock chip has been designed and fabricated, and is fully functional. It implements the shift-register architecture, with on-chip instruction decode, static memory, and drive circuits for each pixel. The chip can be used in a wide variety of displays, all of which will need only four connections for operation.

FSA and interconnection yields have improved steadily, to the point where Alien can currently fill 999 out of 1000 holes with

NanoBlock chips and achieve functional interconnection. Yield improvement is tracking on a predictable path, increasing by better than an order of magnitude every 12 months.

Alien has moved into a new pilot/R&D facility in Morgan Hill, California (Fig. 8). The facility has 21,000 ft.^{2} of space, including 5000 ft.^{2} of class 100 and class 10,000 cleanroom. Designed to speed development, it incorporates a full set of processing equipment and will also be capable of producing qualified production in small quantities as well as development lots.

On the business front, Alien has signed a production agreement to build smart-card displays for Gemplus of France. Gemplus is the world's leader in smart cards, holding over 40% of the market for microprocessor-based cards. Alien's displays will initially be used as numerical readouts for electronic-purse cards, with graphical displays being developed for multifunction cards.

In July, Alien closed an $80 million financing round, consisting of $55 million in equity and $25 million in lease financing for production equipment. In addition to covering operating expenses, the financing will fund the construction and equipment costs of Alien's first high-volume roll-to-roll factory. Also to be located in Morgan Hill, the factory will become operational in mid-2001 and will have an ultimate processing capacity of one million square feet of display area.

Among the new investors are Philips Flat Display Systems and DuPont iTechnologies, both of whom will be actively involved in joint-development activities with Alien.

Looking Ahead

By the time this issue of *Information Display* is printed, Alien displays will be circulating prototype smart cards built by Gemplus. The production qualification for the first volume product will begin in the Q2 '01, using material from Alien's pilot line. Towards the end of 2001, a second qualification will begin, this time using material from the web line in the new volume factory. In 2002, we plan to ramp up production to beyond one million displays per month.

References

[1]S. Drobac, "Fluidic Self-Assembly Could Change the Way FPDs Are Made," *Information Display Magazine* **15**, 12–16 (November 1999). ■

Automated Yield-Management Software in LCD Production

Small differences in AMLCD yields can spell the difference between success and failure, so the leader in yield-management software for ICs created a system for the display industry.

by Ankush Oberai and Samuel Tam

ACTIVE-MATRIX liquid-crystal display (AMLCD) manufacturers can increase yields by rapidly identifying specific problems in their production lines by applying automated yield-management tools similar to those that have been available to the semiconductor industry for years. LCD manufacturing poses a number of unique problems not present in the semiconductor industry, and these challenges must be solved to create a useful yield-management system.

LCD and semiconductor manufacturing do share some significant features. Both depend on a series of complex procedures performed under exacting controls to create sophisticated devices. Multiple structures are fabricated on a single substrate using lithography, deposition, and etch technologies. And unfortunately, the processes are not perfect, and defects can occur that may render the final product useless.

Ankush Oberai *is Vice President of Worldwide Sales and Strategic Marketing at Knights Technology, a division of Electroglas, Inc., 6024 Silver Creek Valley Rd., San Jose, CA 95138; telephone 408/528-3810, fax 408/528-3557, e-mail: aoberai@electroglas.com.* ***Samuel Tam*** *is Director of Worldwide Applications Support at Knights Technology; telephone 408/528-3878, e-mail: stam@electroglas.com.*

The Challenge of LCD Production

There are major differences between LCD and semiconductors that make yield management especially important for LCD manufacturers. Instead of producing dozens or even hundreds of semiconductor devices from a single small substrate, a single large plate of glass is divided into only a few LCD panels. As consumer demand grows for larger and larger displays, the substrates get larger and the number of panels per plate decreases, making yields more critical than ever.

Instead of starting with a nearly perfect silicon wafer as a substrate, LCD panels are based on glass covered with an imperfect coating of amorphous silicon (a-Si). And while semiconductors may have large numbers of components in a single device, they are created in relatively close proximity to each other with room to provide redundant components that can be used as spares in the event that one is defective.

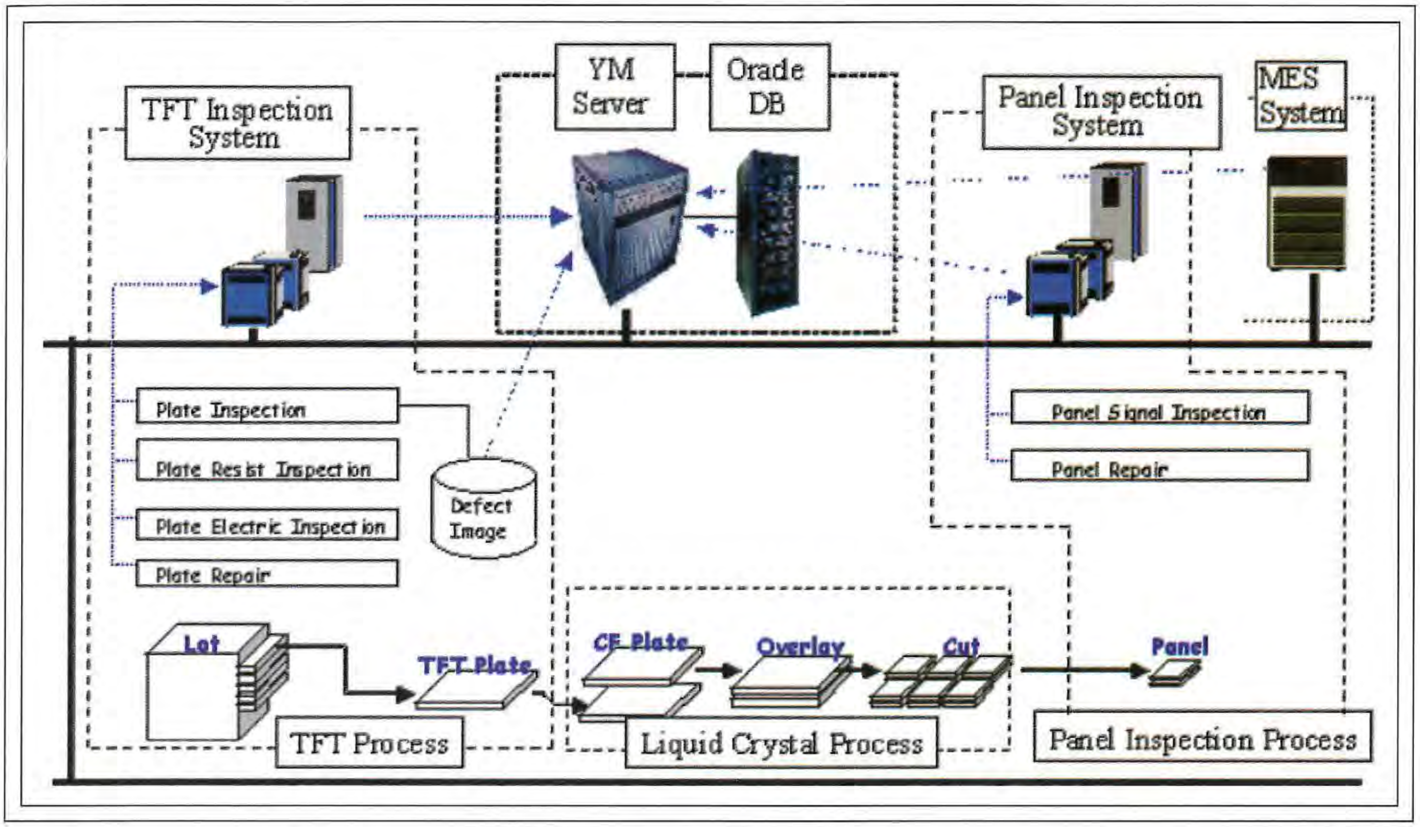
In contrast, the simple transistors of an AMLCD panel are spaced across large expanses of substrate. A 12.1-in.-diagonal LCD panel with SVGA resolution will have 800 × 600 pixels, each of which consists of three subpixels, which means there will be 1.44 million transistors spread across nearly 70 in.^{2} of panel area. A 20-in.-diagonal panel with SXGA resolution (1280 × 1024 pixels) and nearly four million transistors must be created across about 195 in.^{2} To achieve a perfect display, every one of those four million transistors must work. And, in contrast to semiconductor products, there is little room for redundancy: spare transistors lower the aperture ratio, which means less light can be transmitted by the panel.

LCD manufacturers also face the problem of product differentiation. When making a CPU for microcomputers, the specific features and brand reputation of the chip can play a role in unit pricing. Aside from some finer technological points, there is not a lot of difference between AMLCD panels of a given size and resolution, and most consumers don't know which company made the display panel in their notebook computer or desktop monitor. As a result, product pricing is competitive in the extreme, with razor-thin margins.

Much of the cost of an LCD panel is in the manufacturing, and, as a result, profitability is closely linked to yield rates. According to DisplaySearch of Austin, Texas, yield rates for the array process – after the transistors have been fabricated on the panel – are about 96% for 12.1-in. SVGA active-matrix panels. As panel resolution increases, however, there are more components and greater probability of defects. DisplaySearch estimates the yields for 20-in. SXGA panels to be about 85%. Any change in yield rate can quickly have a significant financial impact.

The cost of producing flawless AMLCD panels is prohibitive, and buyers of notebook

0362-0972/00/1611-018$1.00 + .00 © SID 2000



Knights Technology

Fig. 1: Automated yield-management software collects data from all aspects of the LCD manufacturing and testing process. This screen is from the Knights YieldManager™ system.

computers and desktop monitors generally understand that there may be a few pixel defects on their displays. But as the market broadens and reaches less knowledgeable consumers, expectations tend to get higher.

Defects are more noticeable when viewing video than when viewing data applications. According to one PC manufacturer, defective pixels in the display is the leading reason for the return of notebook computers equipped with DVD drives that can be used to watch movies. If consumers – and the companies that produce the products they buy – raise the bar on what is an acceptable number of defects in a display, they will effectively lower the yield rates on existing production lines.

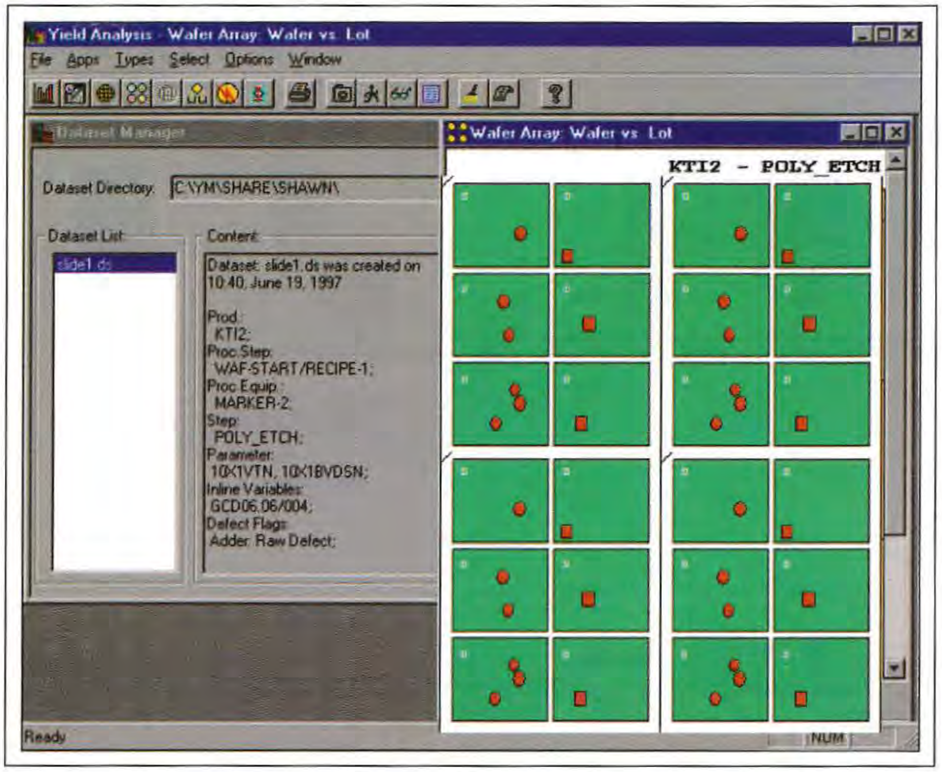
Factors Affecting Yields

LCD-panel production tends to be a highly automated process. Large cassettes hold a number of glass-substrate plates at one time – referred to as a "lot" – and are transported to various in-line production machines. The plates are processed individually, and then held in a cassette for transport to the next machine for the next process.

One key factor determining yield rates is the cleanliness of the production environment. The production lines typically run around the clock, and are brought down for cleaning and maintenance as infrequently as possible. Some processes take a long time to complete, so it can take days for a glass plate to be transformed into a display panel. The lots must be protected against particle contamination the entire time.

The lengthy processing introduces another factor. In the early days of LCD production, there was no way to know if a given panel was acceptable until it was turned on and tested. If a panel failed an early production step, all the subsequent steps represented wasted time and materials. Now, manufacturers have sophisticated testing and inspection equipment that can automatically evaluate panels at intermediate points in the manufacturing process. In some cases, flaws can be automatically repaired. These steps can help reduce the losses due to defective panels. Manufacturers have to balance the need for comprehensive and accurate testing (to identify as many defects as possible) against the need to avoid slowing down production more than necessary and the need to control the capital and maintenance costs for test equipment.

The LCD-manufacturing process can be broken down into three major stages: the array process, which creates the thin-film-transistor (TFT) arrays on the substrate; the lamination of the front and rear glass plates and the injection of the liquid-crystal material; and the separation of the individual panels and the attachment of the electrical connections. Each stage consists of many complex steps. For example, the array process includes multiple passes of thin-film deposition, resist layers, exposure, development, etching, and stripping. There are opportunities for defects to occur at nearly every step of every stage. The defects take different forms, and can be divided into optical, mechanical, and electrical defects. Some



Knights Technology

Fig. 2: *A plate-array view allows users to see if a defect pattern is a one-, multiple-, or every-plate effect.*

of these can be repaired, while others are permanent and may be severe enough to render the panel unusable.

Optical defects are the most common and often the most serious. "Stuck pixel" defects can be either bright or dark – either always transmitting light or never transmitting light. The most common cause of this type of problem is actually an electrical problem: a short or an open circuit in the cell's transistor or signal leads.

Leakage in the individual transistors is another problem. Some of these defects can be corrected in the inspection stage before lamination through the use of lasers to either cut or weld the traces. Similar defects can cause horizontal or vertical lines in the display. Light or dark spots can also be caused by foreign-particle contamination between the glass plates or between the panel and backlight.

Non-uniformity is another major type of optical problem. This can be caused by a non-uniform cell gap, resulting in a liquid-crystal layer that varies in thickness. Or it can be the result of errors in the rubbing process for the liquid-crystal alignment layers. Inconsistent color-filter thickness or incomplete removal of chemical residues can also create uniformity problems.

Mechanical defects can be a problem, too. These include broken glass – which can be caused by mishandling or improper assembly – and broken connections. A typical active-matrix panel requires thousands of electrical connections to the integrated-circuit (IC) drivers that control the image on the display. Improper assembly, errors in alignment of the components, and mishandling can all result in broken connections. It is also possible to introduce a mechanical defect in the final assembly. For example, if improperly assembled, the panel's bezel could obscure a portion of the display area.

Electrical problems are least common and perhaps easiest to correct. These are caused by flaws in the driver circuitry, power supply, and other electrical components used to support the display panel.

Yield Management in LCD Production

The key to maintaining optimum yield rates – and to increasing them even further – is to automatically monitor and analyze panel defects at all points in the production process. This approach has been a standard feature in semiconductor fabrication for years, but has only recently been applied to LCD production.

In this approach, software gathers data from different stages of the manufacturing process in real time. This information can be analyzed to identify trends and patterns in the data, which in turn can lead to the early detection of manufacturing problems and to the development of improved procedures.

In LCD manufacturing, the raw data is already available. Automated equipment has tested the glass plates at various stages – plate inspection, plate resist inspection, and plate electric inspection – in creating the TFTs. Automated plate-repair machinery can provide additional data. And images of the plates can be captured, providing a visual representation of defects. Inspection and process data from assembly processes and final testing and repair of the individual panels provides even more data. All of this data can be passed through to a server where it is stored in a central database for processing (Fig. 1).

Compared with semiconductor fabrication, LCD manufacturing presents systems that serve as both a simpler and more complex basis for constructing a yield-management system. It is simpler because there are fewer steps involved in the manufacturing process. A typical LCD panel may require from 10 to 15 operations, which is far fewer than the 100 or more required for some semiconductor processing streams.

On the other hand, there are some unique complexities. LCD panels have much larger surface areas than semiconductor substrates. As a result, panel images are much larger, and there are more data points from the testing machinery. This translates into more information; defect imaging alone can require more than 7 Gbytes/day, even when using image compression.

Another problem centers on the data-gathering process. In the semiconductor industry, the testing and monitoring equipment is relatively mature and generally adheres to industry standards. In contrast, LCD-manufacturing equipment is not standardized and often uses proprietary designs developed by the manufacturer. As a result, the data available from different pieces of equipment may be in a proprietary format and require processing before it can be incorporated in a central database.

YieldManager™ System

To the best of our knowledge, the only full-featured automatic yield-management system that has been applied specifically to AMLCD manufacturing is the YieldManager™ system from Knights Technology. Knights, the leading software supplier of yield-enhancement tools to the semiconductor industry, designed the system for the early detection of yield-loss areas. A system tailored to AMLCD manufacturing was installed several months at ago at the facility of a major Japanese manufacturer. The results have been positive.

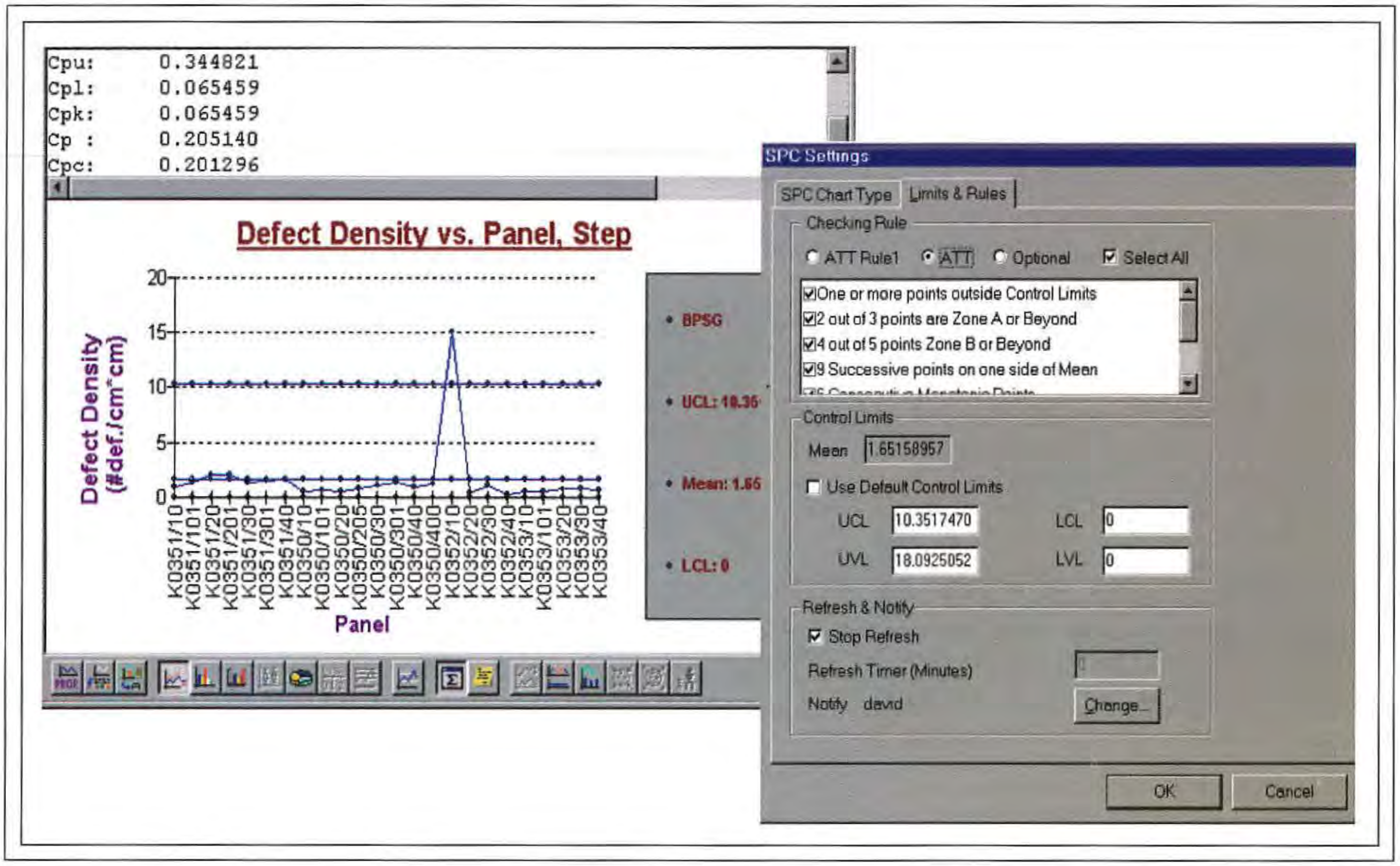
The system captures data from all testing and repair machinery in the fabrication process. Because some of this machinery is of proprietary design, Knights created custom loaders that can read the data from inspection machines and then format the data for loading into the shared database.

The system automatically analyzes this data using a number of techniques. Partitioning is used to determine which defects were added to the plate since the previous data collection. Cluster analysis is applied to distinguish between random and non-random defects, which in turn can provide insight into the source of the defects. Repeater-defect detection is designed to identify defects that occur in the same position on most or all of the plates. And sample selection is able to determine whether or not a defect identified by an inspection machine is in fact a defect, or simply a slightly out-of-specification element on the plate.

By assembling data for individual plates throughout the fabrication process, the system is able to provide a number of different ways to analyze the information and present the results so that the large amounts of data can be easily viewed and understood. These include graphic maps of defects on plates, as well as a wide range of graphs and charts.

For example, an operator can choose to look at the defect maps for a single plate and see where defects are introduced by specific steps in the process. Defect maps for multiple plates can also be compared (Fig. 2). This allows the operator to distinguish between problems that occur on a single plate and those that occur in the same location on multiple plates. If the location repeats, it can point to a flaw in a specific piece of machinery; maintenance or repair may eliminate it as a source of defects, resulting in an increase in yield rate.

The data can also be analyzed automatically by the system. For example, the system can set control limits for statistical process control (SPC), or custom limits can be set for a process. The observed defects can be charted against these limits, providing a graphic representation that makes it quick and easy to review the results (Fig. 3). The system can automatically send e-mail notification of any warning or limit violation. This provides for



Knights Technology

Fig. 3: *Statistical-process-control (SPC) charts make it easy to spot cases in which predefined limits have been exceeded.*

Circle no. 11

prompt attention to any production problem that may increase the number of defects. The system is also able to track equipment-maintenance cycles, and can automatically provide notification when maintenance is due.

The system allows the user to customize the displays to present the specific analysis that is desired, and any analysis screen can be saved as a macro, so the analysis can be repeated with a new set of data. Results can then be e-mailed to other recipients or converted to Microsoft Word or HTML documents that can be viewed with any Web browser. Each field in the database is searchable, and can be queried for lot, plate, or panel results using multiple search criteria.

YieldManager™ is a client-server system that uses TCP/IP protocol across standard Ethernet connections. As a result, it is easy to integrate into an enterprise-wide computing environment, making the real-time data and results available to all who need access to the information.

The Payoff

Trial runs have demonstrated that access to real-time yield-analysis data can have a significant impact on production yields in LCD manufacturing. Production errors on the line were reduced and defects were reduced. The automated analysis and notification features shortened the time required to recognize and correct situations that could have resulted in lower yields. The detailed tracking of the process at every step – from TFT formation through lamination and injection to panel separation and inspection – provides a rich vein of data that can be mined not only to monitor current line production, but also point the way for further improvements.

Knowledge is indeed power, and a yield-management system can be a powerful tool that can have a positive impact on the profitability of LCD-panel production. ■

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.

Microvision's SS200 series of display analysis equipment allows you to precisely, automatically and quickly measure display performance. And with many test laboratories currently using the SS200 series as their standard test system, shouldn't you?

The SS200 series includes the SS210, SS220 and SS230 systems. Each system allows for modular field upgrades for increased functionality - Buy what you need, when you need it! Each system may be used on any display type from CRTs & FPD to projection, cockpit and microdisplays. The familiar *Windows*-based GUI makes the equipment easy to use and personalize. All versions come with the time tested Spotseeker five-axis positioning stage integrated into all test sequences. Each system is a complete turnkey system with a computer, 5-axis positioner, monitor, software, spectrometer, and camera system. For automatic testing to ISO, VESA, NIDL & TCO specifications, or comprehensive analysis for engineering and quality control requirements, the SS200 series has the system for you!

SS210 System:

The SS210 package has a CCD camera to provide spatial measurements such as Line Width and MTF. It includes an integrated spectrometer for spectral analysis and color measurements and also includes an optional response time measurement capability.

SS220 System:

The SS220 system is the perfect choice for flat panel testing. It features spectrometer-based, off-axis measurements, color analysis, contrast ratio and luminance testing.

SS230 System:

The SS230 (pictured above) is a combination of the SS210 & SS220 system, resulting in the most comprehensive test system available. All tests are performed at NIST traceable accuracy.

Used by Test Laboratories Worldwide

MICROVISION

Dedicated to the Needs of the Display Industry

550 High Street, Auburn, CA 95603 USA
Tel:(530) 888-8344 * Toll Free: (800) 931-3188
Fax: (530) 888-8349 * Email: info@microvsn.com
Web site: www.microvsn.com

International Representatives:
Japan - ARGO CORP., 06 339 3366
Taiwan - SUPERLINK TECH., 886 2 2698 3456
Korea - B & P INT'L, 02 546 1457
China - HUADONG, 86 25 5319677

Circle no. 12

25 Years of SID in Japan

SID's Japan Chapter has helped transform the Asian economy and produce the products that have ushered in the Information Age.

by Aris Silzars, Chuji Suzuki, Shigeo Mikoshiba, and Makoto Maeda

TIME PASSES, changes take place – almost imperceptibly from a day-to-day perspective. But from the broader perspective provided by the passing of a quarter of a century, these seemingly imperceptible changes work like the grains of sand in an hourglass to create a new world in which much is different. So it has been with the Society for Information Display and the founding of the Japan Chapter in 1975.

When, in 1973, Sharp began volume production of the first LCD-based electronic calculator using the dynamic-scattering liquid-crystal mode it had licensed from RCA, it resurrected an orphaned technology and changed the Japanese electronics industry forever. Even more significantly, it laid one of the foundation stones for the age of personal and portable electronic appliances that continues to change the world. So perhaps it was appropriate that when the SID Japan Chapter was formed 2 years later, all the officers were Sharp employees.

Coincidentally, my own involvement with SID and my first visits to Japan also began during this period. I can still recall the extensive planning and preparation that went into these visits. Without the benefits of an established SID chapter, it was much harder to find the appropriate contacts within Japanese electronics companies. Often, many letters had to be passed back and forth before suitable arrangements could be made.

With the establishment of the SID Japan Chapter, the growth of the display industry in Japan, and the ever-increasing participation by Japanese display scientists and engineers in SID activities, the communications and travel barriers have all but disappeared.

SID has responded to the changes taking place in the world display community by

Chuji Suzuki

Fig. 1: The first officers of the SID Japan Chapter met in July 1974, about a year before the Chapter's founding, in an office at the Sharp Central Research Labs in Tenri. From right to left are Chuji Suzuki, Sanai Mito, and Toshio Inoguchi.

Aris Silzars is President of SID, Chuji Suzuki is a SID Fellow, Shigeo Mikoshiba is Secretary of the SID, and Makoto Maeda is Japan Chapter Chair. They may be contacted through SID International Headquarters; telephone 408/977-1013, fax 408/977-1531, e-mail: office@sid.org.

0362-0972/00/1611-024$1.00 + .00 © SID 2000

Chuji Suzuki

Fig. 2: Alan Sobel, Joseph Markin, Sanai Mito, John Flannery, and Howard Stark (from right to left) attended the 1977 SID Symposium in Boston.

becoming more international in scope. About 10 years ago, the growing importance of the Japanese display industry led the Society to affirm its commitment to global display interests through the creation of Regional Vice-Presidents, one each for Asia, Europe, and the Americas. The encouragement and approval of the Japan Chapter were key to facilitating this change.

Thus, on the occasion of their 25th anniversary, we salute our colleagues in the Japan Chapter. From those modest beginnings in 1973 the Chapter has grown to approximately 800 members. The Chapter's International Display Workshops has become one of the world's premier technical conferences. In addition, the Chapter periodically hosts the International Display Research Conference. Members of the Japan Chapter serve with distinction on the SID Executive Committee and the SID Board of Directors, and are key participants in various SID committees.

Over the last quarter of a century, the Japanese display industry has grown to include the participation of almost every major electronics company – and many smaller ones as well. Through the efforts of our SID colleagues in Japan, the Information Age, the Japanese electronics industry, and the world display community have become inextricably linked. Twenty-five years is not so long ago, but these sweeping changes could not have been foreseen then. We are grateful to those early founders who took the first bold steps along this productive path and helped the rest of us to follow. We offer our congratulations to our colleagues in Japan for 25 years of progress and growth. May the next quarter-century be equally productive!

– Aris Silzars

Establishment and Growth

It has been 25 years now since a new SID chapter was established in Japan. While my memory is still clear, I wish to record my fading reminiscences of the Japan Chapter in its infancy.

In the early 1970s, a large number of excellent papers on display technology were presented by many large companies and universities in Japan, but they were seldom presented overseas because of economic conditions.

Professor Akio Sasaki of Kyoto University unexpectedly attended the display-device conference sponsored by the IEEE's Electron Devices Group in 1972, and then stopped at the Zenith Corporation on his return trip to meet Mr. Joseph Markin and Dr. Alan Sobel. I imagine that he discussed the realities of the development of display technology in Japan, unaware that this would lead to the birth of the SID Japan Chapter 3 years later.

After he returned to Japan, Sasaki visited Dr. Sanai Mito of Sharp in Tenri, Nara, who

Takehiro Kojima

Fig. 3: The first meeting of the Organizing Committee for Japan Display '83 was held on December 9, 1981. Standing is the late Dr. Koichi Miyaji (Conference Chair); Dr. Akio Sasaki (Program Chair) and Dr. Shunsuke Kobayashi (Treasurer) are on his left.

Takehiro Kojima

Fig. 4: SID Board members gather before the Japan Display '83 farewell party.

told him that Markin wished to write some papers concerning display-device research and development in Japan for an issue of *IEEE Transactions on Electron Devices*, and that Mito would join Markin in presenting some papers at the 1975 SID International Symposium.

It was probably Markin, acting on behalf of the SID Board of Directors, who explored with Mito the possibility of establishing a new SID chapter in Japan, and asked Mito to serve as Overseas Program Advisor for the SID Symposium, according to a memo written by Mito. Because Mito was proficient in English and a gentleman with very good manners, and because he had a good grasp of details, the key people on the SID committees found it easy to discuss with him the concrete elements of establishing a new chapter.

Immediately upon his return to Tenri, Dr. Mito – who was our superior – ordered Mr. Toshio Inoguchi and me to set up our new chapter within the year. This included the writing of bylaws and the creation of business and financial plans for submission to the SID Board. Naturally, Dr. Mito became a candidate for Chair of the new chapter, and then asked Inoguchi to be Secretary and me to be Treasurer. This was very convenient because everyone worked in the same building. Now you can understand how it came to be that all three of our first chapter officers worked for Sharp (Fig. 1).

The bylaws and the 1975 directory were completed by the end of October 1974, and four influential men joined the Executive Board of the Japan Chapter: Prof. Koichi Miyaji, Prof. Akio Sasaki, Prof. Shunsuke Kobayashi, and Dr. Iwao Ohishi. Dr. Gentaro Miyazaki was elected as Director acting on behalf of the Japan Chapter. He stayed in the U.S.

The SID Board of Directors approved our plan in May 1975, and the new chapter's first formal activity was a technical meeting on June 13, 1975, that included reports on the 1975 International Symposium. The meeting, held at the Sharp Building in Tokyo, attracted 60 persons (at that time, there were about 40 members in the SID Japan Chapter). The meeting became an annual event, and it is still held in the same hall in the Sharp Building every year.

As Treasurer, I became anxious about paying for postage and the rental of our meeting room because I had not yet received the entire budget allocation for 1975, which consisted of a $250 establishment fund, the member rebate, and a chapter rebate (at that time, the membership fee was $15). Fortunately, some of the activities of the new chapter were supported by Sharp at first. Despite my concerns about finances, our chapter activities continued.

In Osaka, on July 16, we had our second technical meeting. Our guest was Dr. Robert Adler of Zenith, inventor of the first practical television remote control. About 70 persons attended. We awoke to the fact that we had not yet held the important General Meeting for 1975, so we held it in Tokyo, on September 23, 1975. Our business and financial plans were adopted. It was important to my function as Treasurer to increase the member-

Takehiro Kojima

Fig. 5: A combined SID HQ/Japan Chapter meeting was held for the first time in Japan on the opening day of Japan Display '89 in Kyoto, October 16, 1989.

Takehiro Kojima

Fig. 6: The first SID Board of Directors Meeting in Japan was held in Hiroshima, October 11, 1992.

ship, so I wrote some articles about papers given at the SID International Symposium for Japanese technical magazines every year after that. As a result, our membership increased rapidly.

Dr. Mito, our Chair and Overseas Advisor, was active in attending the annual SID Symposium (Fig. 2). He helped various Japanese speakers, took care of Asian attendees, and remained a member of the SID Board, staying in the U.S. every year until he eventually retired. From the Japan Chapter's first year, starting in March 1975, Mito ran an oral-presentation training program for Japanese speakers which has continued to this day.

At our General Meeting on July 6, 1976, again at the Sharp Tokyo building, the same three officers and four Board members were re-elected, and the candidates for 1977 were also selected: Miyaji as Chair, Suzuki and Kojima as Secretaries, and Okada as Treasurer. The Board increased to 12 persons, making it more active and powerful. Our membership had increased rapidly to 60, so our financial condition improved. Our balance was about $360 (about 100,000 yen at the then-existing exchange rate) by the end of October. The SID Japan Chapter had become established, and it grew up in a hurry.

In the year 2000, I am once again a newly elected Japan Chapter officer, as I was a quarter-century ago. But there are many differences. Among them is the fact that the Chapter is a little bigger now: there are nearly 800 members.

– Chuji Suzuki

Looking Back

SID was established in 1962, 38 years ago. The SID Japan Chapter was born 13 years afterwards, covering 66% of the total SID history. In these 25 years, the advances in display technology have been enormous. In Japan, it is frequently said that "semiconductors are rice for industry." This means that semiconductors are as important for the well-being of Japanese industry as rice is for the well-being of the Japanese people. Recently, many people are saying, "Displays are the second rice for industry."

Many noteworthy events related to the display industry and the Japan Chapter of SID have taken place in the last 25 years. Some of the most significant, as I recall them, are as follows.

The Beginning of Japan Display. The name was changed later to Asia Display – in 1983. By organizing Japan Display [the name for the International Display Research Conference (IDRC) when it was held in Japan] every third year, Japan became a major player in the display community. Japan Display also made it possible to publicize a large number of research activities in Japan easily (Figs. 3–5).

Establishment of the Asian Symposium on Information Display (ASID) in 1993. Cooperation between the Korea, Taipei, Beijing, Hong Kong, and Japan Chapters promoted SID activities in Asia.

Initiation of the International Display Workshops (IDW) in 1994. The IDW, which is held every fall in Japan, has a special feature. Session Chairs and Program Committee members for about 10 workshops pursue the task of organizing the technical program. In this manner, the most up-to-date coverage of leading-edge topics can be included.

Holding SID International Symposium Asian Program Subcommittee Meetings. The pre-selection of papers in Tokyo makes it unnecessary for the 40 Asian subcommittee members to travel to the U.S. paper-selection meeting. All of these activities have been initiated or fostered under the strong leadership of Professor Heiju Uchiike.

In addition to these events, the Japan Chapter co-sponsors 12 domestic meetings every year. The co-sponsorship with other organizations widens the range of researchers involved and also provides them with enough opportunities to make presentations. Since there is no paper-selection procedure for these domestic meetings, anyone can submit research results – even preliminary results in which the presenter may not have full confidence. Audiences can offer advice and comment during the discussion period. But even without the paper-selection process, the academic level of the presentations is kept high. This is accomplished by allocating a relatively long time, typically 30 minutes, to each presentation and by requiring the submission of six-page manuscripts, which ensures that authors spend appreciable time on the preparation. This is in contrast to SID's international conferences, in which speakers have only 20 minutes or less, too short a time for detailed discussion.

Because of the Japan Chapter's intensive activities, the number of chapter members kept increasing, but only until 1991, when the number peaked despite the steady increase in the number of persons engaged in the display industry. This is mainly due to the language barrier, since the official language of SID events is English. But it is also true that engineers can now acquire most of the information they need without becoming SID members.

SID Japan Chapter jubilee

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.

To stimulate membership growth, the Japan Chapter recently adopted a system by which members can pay their membership fees with cash cards. The ability to pay through the Web may simplify the process even further. The introduction of an automatic renewal system – in which membership continues automatically every year unless the member asks for discontinuation – should also be considered. Most academic societies in Japan successfully use this system.

The Japan Chapter hopes to promote display industries in Japan, in Asia, and throughout the world.

– Shigeo Mikoshiba

Status and Outlook

Since the SID Japan Chapter's foundation, its membership has been on the rise and now numbers 800. This expansion suggests that people have high expectations for display technology and the display business in this information age. Behind our chapter's success, there have been tremendous efforts made by our mentors, including Professor Sanai Mito and Professor Koichi Miyaji, both of whom passed away last year. Although their deaths were a great loss to us, others have carried out their will and devoted themselves to growing the institution.

Almost every month, we host many technological meetings in Japan. We are proud that no other chapter in the world does this more aggressively than we do.

Our activities are not confined within our borders. Japan Display, established in 1983 as a Japan-based international SID conference, became Asia Display in 1995. Asia Display was held in Seoul, Korea, in 1998 and will be in Nagoya, Japan, in 2001. We are lending a helping hand to our neighboring chapters that want to revitalize their own activities.

We also wanted to help Japanese scientists and engineers publish their own ideas, and we appealed to members of the global community for their cooperation. The International Display Workshops (IDW), which was launched in 1994 and has been held every fall since then, serves well for this purpose. It collects a variety of excellent papers from all over the world and attracts many attendees. For the conference's seventh convocation – scheduled for this November in Kobe, Japan – 1000 attendees are expected to come from 20 nations. The IDW has now become one of SID's major events. Its success is based on the enthusiastic efforts of a great many volunteer members.

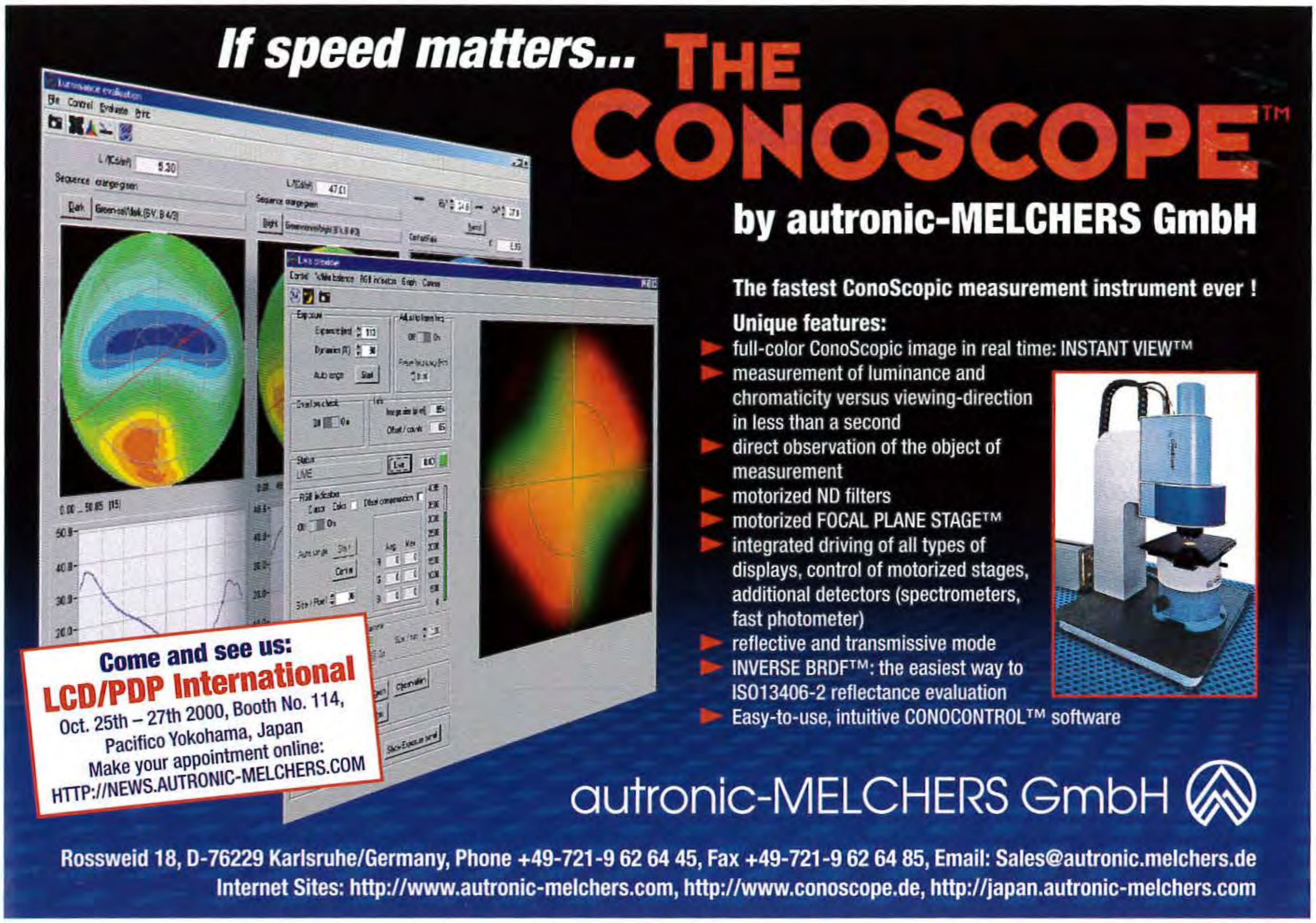
Members of the SID Japan Chapter are working to develop basic display technologies, such as CRT, LCD, PDP, EL, and apply them to actual products. New products combined with the latest display technologies appear in the market every year.

I believe that this dynamic technology development and product creation comes from the openness that was created after we tore down barriers and asked scientists, engineers, manufacturers, and users in different fields to come forward with their own ideas, exchange information, and enlighten each other. If we had stuck to the old secrecy principle, our development work would never have enjoyed such great success. Our openness is the key to success in the age of information, in which people seem continually thirsty for new displays featuring various cutting-edge technologies.

We need many young, talented people. The electronics industry in Japan that used to develop display devices now needs to obtain displays from a variety of sources because it now aims at other ambitious goals, including display systems and fundamental R&D. These industry segments are large compared with the membership of the SID Japan Chapter, and we want to attract the engineers working in these segments. For that purpose, the Chapter has launched a system of student support to commemorate our 25th anniversary. We pay some of the traveling expenses for these talented young people so that they can attend SID events and present their ideas in front of a large professional audience – a rare but quite important experience for them.

The SID Japan Chapter will do its utmost to help members progress in their studies and businesses, and give them more opportunities to exchange unique information about display technology. We hope that all of you reading this celebration of the Japan Chapter's jubilee will invite your friends and colleagues to join SID. With fresh power and knowledge, I believe we will be able to continue to explore the unknown together.

– Makoto Maeda



Circle no. 14

Circle no. 15

conference report

The First IDMC and FPD Expo Korea Attract More Than 1000 People to Seoul

Korea to command 40% of TFT-LCD industry says John Koo in Keynote; Rainbow and Philips show 37-in. TFT-LCD to compete with PDPs.

by Ken Werner

A THOUSAND people came to the Sheraton Walker Hill Hotel and Conference Center in Seoul, Korea, from September 5th to 7th to attend the first International Display Manufacturing Conference (IDMC) and the accompanying trade show, FPD Expo Korea (Fig. 1). IDMC was sponsored by the Korea Chapter of the Society for Information Display and the Korean Information Display Society, along with other organizations; FPD Expo Korea was sponsored by SEMI Korea and the Electronic Display Industrial Research Association of Korea (EDIRAK).

In his IDMC keynote address, "Future Prospects of the Flat-Panel-Display Industry in Korea," John Koo, Vice Chairman and CEO of LG Electronics, Inc., commented that not long ago, the CRT was the pride of the Korean display industry and Korea had only 5% of the LCD market. By the end of last year, Korea's LCD market share was 31%; by the end of this year it should be 38%.

The display is the window to the world of digital information, and the 14-in. CRT monitor is no longer adequate to do the job. The displays we need now must show the information we obtain from digital technology networks on a large scale and at high resolution, and they must be light, thin, and low in power consumption.

This bodes well for the FPD industry. An IDC Japan Study done in April 2000, said Koo, predicted a $28 billion FPD market by the end of this year, growing to $65 billion in 2005. PDPs will account for 23% of the FPD market in 2005.

In a short time, the Korean FPD industry has come to dominate that market. In Q2 '00, Samsung captured 21% of a worldwide FPD market worth $3.7 billion, according to an August 2000 report from DisplaySearch, said Koo. LG had 14% and the leading Japanese supplier, Hitachi, had 10%.

Koo identified several success factors that contributed to the Korean industry's achievement in surpassing Japan's market share in 1999 and dominating the TFT-LCD industry:

1. The willingness to invest aggressively even in the midst of the Asian financial crisis.
2. A commitment to TFT-LCDs as Korea's most promising industry.
3. The ability to transfer technology from a strong semiconductor industry.

Ken Werner

Fig. 1: One thousand people came to the Sheraton Walker Hill Hotel and Conference Center in Seoul to attend the first International Display Manufacturing Conference and FPD Expo Korea.

Ken Werner is editor of Information Display.

Ken Werner

When Korean companies design products for the domestic market, they may not look like those designed for the international market – as is the case for this LG NeTee photographed at the Techno Mart across from the Gangbyeon subway station.

But the Korean industry does have some weaknesses. It is highly dependent on the importation of manufacturing equipment and critical technologies. And Korea needs to develop its own cutting-edge core technologies – not just manufacturing technologies, which it has done well.

"I believe these barriers will be overcome," said Koo, and "that the Korean share [of the TFT-LCD market] will grow to 44% by 2005." Samsung and LG will each hold about 20% of the market, even with Taiwan's aggressive development of their own TFT-LCD industry.

LG's goal is to become the leader of the global FPD industry and the leader in digital electronics and communications. The company sees the core of its business as mobile networks built around IMT-2000 and home networks (DTV). FPDs are crucial to this vision, and the company intends to invest $5 billion in LCDs and $1 billion in PDPs between now and 2005.

In answer to a question from Sungkyoo Lim of Dankook University (who is also Secretary General of IDMC 2000), Koo said that an LG 40-in. PDP TV is commercially available now. The current 60-in. prototype still needs a cooling fan and is too noisy for a domestic environment. A fanless design should be finalized this fall, and a 60-in. TV should be commercially available next year.

Responding to another question, Koo said that after 2005, LG and Samsung would be investing heavily in production infrastructure and materials. Korea is not likely to produce manufacturing equipment at the level of Japan before 2005, but Korean semiconductor-equipment companies are doing some work to adapt their technologies to display manufacturing.

In the other keynote address, "Display Manufacturing: The Next 10 Years," Aris Silzars, President of SID, observed that display technology is now advancing at a much slower rate than computing hardware and software, *i.e.*, limitations in display technology are slowing the progress of computing and communications devices. This is both a challenge to the display community and a source of great opportunities.

Emphasizing one of his favorite themes, Silzars said, "Breakthroughs only occur at the materials level." The breakthroughs we need are those that will provide improvements in performance – such as brightness, resolution, and color – in comparison to other media, and the ability to manufacture displays with these improvements at a reasonable price.

Since display breakthroughs occur at the materials level, progress in the display business is usually predictable. To prove his point, Silzars showed some slides he used in a presentation 15 years ago; most of the prognostications over a wide range of topics were remarkably accurate. A notable exception was the belief, widely held at the time, that teleconferencing would become extremely popular and would reduce the need for business travel and personal contact. In fact, the opposite has happened.

Teleconferencing – which Silzars defined broadly to include e-mail and the various forms of Internet-based communications – has indeed exploded. But it has allowed us to form new relationships, the nurturing of which require personal contact. By helping us form groupings based on interest rather than geography, electronic communications requires us to travel more, not less.

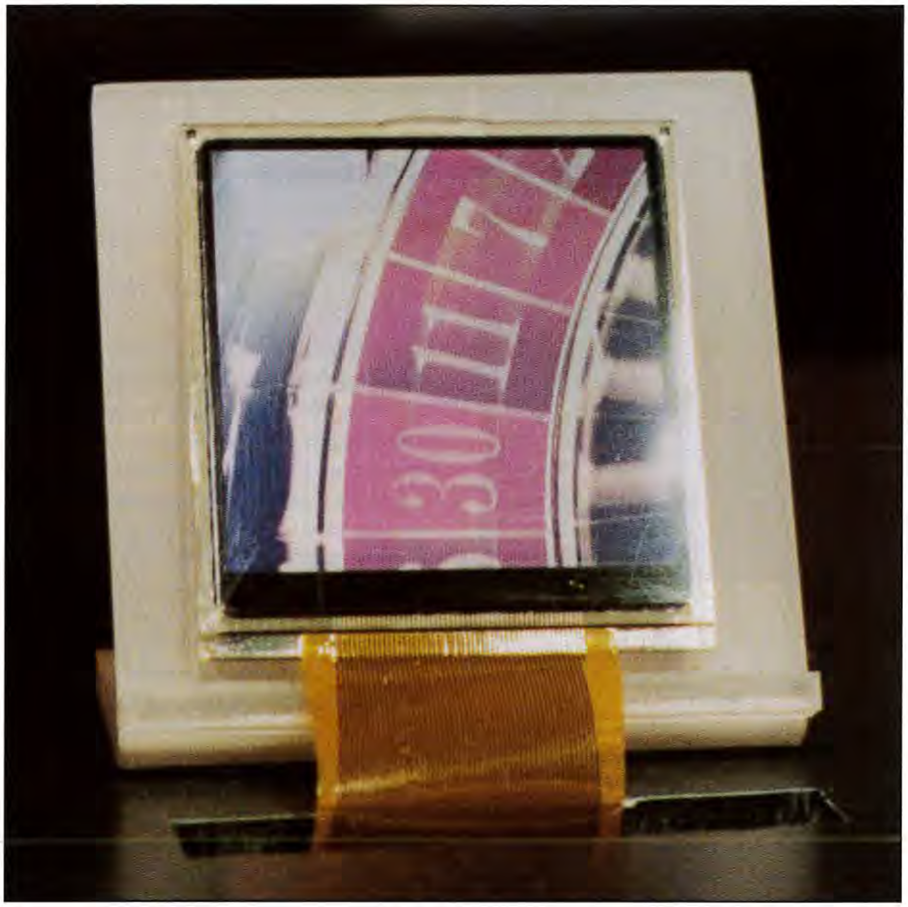
What wasn't on the 1985 slides at all, Silzars pointed out, was any mention of the Internet. That's a development that people didn't foresee. Silzars sees the proliferation of Internet appliances as a large growth area for displays. The main characteristics of these appliances are ease of use, instant access, and low cost, the other side of that coin is that the highly touted "convergence" of TV and the Web will be limited. People relate to a TV and a Web terminal differently, they use them differently, and the displays they will prefer for the two functions have different characteristics.

"While the major product categories such as television and desktop computers will continue their predictably steady growth, the new products such as PDA and other Internet appliances will be the fertile ground that will allow new display technologies to be introduced," Silzars said. "The greatest successes will be the result of strong international relationships that will facilitate the transition of innovative new technologies into products.

Silzars concluded with a thought that was echoed in John Koo's presentation: "It is only through such international cooperation that it will be possible to meet the accelerating demands of the Internet Society for displays that are larger, brighter, more versatile, and lower in cost."

Exhibits Plus

Forty companies participated in FPD Expo Korea, some with extensive and elaborate booths. ***Samsung Electronics*** occupied the left wall as one entered the Sunflower Room,



Ken Werner

Fig. 2: Samsung Electronics showed a prototype 2.04-in. reflective LTPS TFT-LCD with 240 × 240 pixels and a 15:1 contrast ratio for applications such as IMT-2000 cellular phones and camcorders.

which served as the main exhibit hall. Their sign prominently featured the new "wiseview" logo featured at the SID show in May. A full range of TFT-LCDs was being shown, but the first two were of particular interest.

First was a 2.04-in. reflective low-temperature-polysilicon (LTPS) TFT-LCD with 240 × 240 pixels that could show 262,000 colors. The prototype's contrast ratio (CR) was 15:1 with the front light off and 10:1 with it on. When the front light is the sole illumination for the display, the luminance is 5 cd/m^2. I did not see the display in this mode, but it was impressive under bright spotlights (Fig. 2). The color gamut was obviously limited, but the white was bright, without any obvious tint, and the colors seemed well saturated. The pixel density was 166 ppi, and the display used the mixed twisted-nematic (MTN) mode. Samsung intends the display for applications such as IMT-2000 cellular phones and camcorders.

Next in line, and perhaps even more impressive, was a 6.6-in. UXGA TFT-LCD technology demonstrator mounted in an e-Book mock-up (see cover photo). With a pixel density of 302.4 ppi, luminance of 340 cd/m^2, CR of 200:1, and optical response time of 40 msec at 25°C, this display was stunning. It uses a two-channel 30-pin LVDS interface. Chi Woo Kim, the designer of the display, said it uses amorphous TFTs and has an aperture ratio of 34%. With these specifications, the display almost certainly consumes too much power to be used in a practical battery-powered product, and Kim said that a commercial e-Book display would probably have less than UXGA screen resolution.

This is the first e-Book display (product or prototype) I've seen that makes aesthetic and ergonomic sense. (A monochrome version would be appealing for straight text and black-and-white illustrations.) When one sees an e-Book mock-up with the display limitations removed (except for screen size), it shifts the burden to the software and system designers.

In simply presenting various full-sized pages on the relatively small display, type size on the mock-up became too small for comfortable reading, which had nothing to do with the limitations of the display and everything to do with the human eye's visual acuity. Designers will either have to reformat pages with fewer words per page (as book designers do when designing the paperback edition of a hardcover book), arrange for presenting a half-page at a time with suitable reformatting, or some similar approach. This must be done while keeping type size and line length within the comfortable range.

Also among the units on display was Samsung's idiosyncratic 17-in. SXGA Model LTN170E4 TFT-LCD panel intended for high-performance monitors, engineering workstations (EWS), and multimedia terminals. This very nice panel has a 300:1 CR, 30-msec response time, 200-cd/m^2 luminance, 16.7 million colors, and 160° viewing angle both vertically and horizontally. Monitors with this panel are selling for $1500 *vs.* the more typical 18-in. models that cost $2500, IDC's Bob O'Donnell told ID.

The largest AMLCD that Samsung showed was the 24-in. WUXGA Model LTM240W1. With a 500:1 CR, 400-cd/m^2 luminance, 30-msec response time at 25°C, and 170° viewing angle (H and V), this display exhibited beautiful still images. Moving images were not shown.

Adjacent to Samsung Electronics' exhibit, but certainly not to be confused with it, was the stand of ***Samsung SDI*** (the competition between Samsung divisions has sometimes been intense). Samsung SDI showed a 1.2-in. passive-matrix organic EL display with small-molecule phosphors intended for cellular phones. Six of the displays were being shown in demo cellular phones made by Samsung Electronics.

This OLED prototype is a two-color 64-gray-level device. Eui-Yeul Park, Senior Engineer on the OLED Team, said a multicolor version of the display will be available

Ken Werner

Fig. 3: LG Electronics showed its 60-in. WXGA plasma-display panel, with 500 cd/m², 16.7 million colors, and a 600:1 contrast ratio.

to OEMs in June 2001, with mass production beginning during the year. Park said he expects the production unit to be cheaper than an equivalent TFT-LCD. An active-matrix unit will follow the passive-matrix one, he said. The size of the OLED's active area is 28.14 × 14.50 mm, and the substrate size is 38.91 × 27.99 mm. The display has a 128 × 64 dot matrix, 82.6% aperture ratio, a CR greater than 100:1, 1/64 duty cycle, 100-cd/m² luminance, 3.7 grams of mass, and is 3 mm thick.

Next to the OLEDs, Samsung SDI was showing 37- and 42-in. WVGA PDP TVs. The 42-in. had a luminance of 550 cd/m² and a CR spec of "greater than 900:1." Although the unit was bright and contrasty, there were motion artifacts (loss of definition and edge break-up). The 37-in. had a luminance of 500 cd/m² and a CR spec of "greater than 650:1." The motion artifacts were less noticeable on the 37-in. than on the 42-in. (and the pixels were closer together), which made the 37-in. the more watchable display, to my eye at least.

LG Electronics showed its 60-in. WXGA PDP, with 500 cd/m², 16.7 million colors, and 600:1 CR (Fig. 3). There were some motion edge effects but, overall, the panel was impressive and watchable. In his keynote address, John Koo had said the fan noise from this unit was too loud for a home environment. It didn't sound bad to me at all, but I was listening in the noisy environment of the show floor.

LG's 40-in. PDP in conventional VGA format was impressive for its 850-cd/m² luminance (with 600:1 CR), which was striking. Motion artifacts were visible, as well as some noise not related to motion.

The adjacent ***LG.Philips LCD*** booths housed selections from that company's range of LCDs for notebook, monitor, TV, and automotive applications (Fig. 4).

Hyundai Electronics showed a full range of competitive monitor and notebook TFT-LCDs, including a 15.1-in. SXGA+ (1400 × 1050) unit weighing 650 grams and delivering 150 cd/m² with a 200:1 CR.

Most impressive was the Model HT118E22 monitor with an 18.1-in. SXGA TFT-LCD using Hyundai's proprietary Fringe Field Switching (FFS) technology. The monitor had a 170° viewing angle (H and V), a luminance of 200 cd/m², a CR of 400:1, and 16.7 million colors. The video looked good, with little smearing, despite the claim of a modest 50-msec total response time. A paper on FFS technology was presented at the Asia Display conference held in Seoul in 1998; the monitor was being introduced here at IDMC.

Wooyoung (the Korean company whose slogan is "Japanese Quality; Taiwanese Price; Challenge to the World!") is a maker of backlights and LED lighting for traffic signals, illumination, signage, and architectural accents. The company was showing a range

Ken Werner

Fig. 4: LG.Philips LCD showed its line of TFT-LCDs at FPD Expo Korea. The 60- and 40-in. plasma displays of sibling company LG Electronics can be seen on the far wall.

Rainbow Displays

Fig. 5: Rainbow Displays and Philips FDS demonstrated this 37-in. WVGA LCD TV with a viewing angle of almost 180°. The display consists of three tiled panels, each of which is in portrait orientation, so all the tiling seams are vertical. The seams were invisible under most conditions.

of backlights for camcorders (2.5-in. diagonal) and PDAs (4.1-in.), monitors (24-in. diagonals with 16:9 aspect ratios), and information boards (30-in. diagonals with a luminance of 200 cd/m^2) at a small-quantity price of $2400.

Cleverly, the company has adapted its backlights to be used as light panels behind photographs and printed materials to make them luminous. The backlights are thinner than conventional light panels.

Also shown was the FBU-24 prototype, a 24-in. flat mercury-free discharge lamp for backlighting, with a surface luminance of 5600 cd/m^2 and a brightness uniformity of 92%.

Another Samsung company, ***Samsung Electro-Mechanics***, is energetically developing its microdisplay-based projection engine especially for rear-projection applications, said R&D Manager Sang K. Yun. On display to demonstrate the engine were a 25-in. monitor and 720p HDTV set. The engine is sampling now, Yun said, with volume production set for next year.

EO-PTG was showing a laser separation machine developed by Florida-based PTG. The machine will either cut or scribe display glass, depending on process settings. Team leader Jong-Moo Lee said the company has customers in Korea and Taiwan. The Taiwanese customer is HannStar, and Frank Yang, an engineer in HannStar's Cell Process Department, had stopped by for a customer-supplier talk.

Yang told *ID* that HannStar currently uses a scribe-and-break process to separate its 14- and 15-in. PC and monitor LCDs; the company is evaluating the PTG machine for a possible production role. Yang and Lee were energetically discussing questions of scribe speed and process variables. (HannStar is focusing on laser scribing rather than cutting, said Yang.)

One of the most interesting displays was not in the main exhibition hall at all, but appeared in the lobby of the convention area in what amounted to an extended author interview. The display, by ***Rainbow Displays*** and ***Philips FDS***, was a tiled display consisting of a single row of three AMLCD panels (Fig. 5). The individual panels were in portrait orientation, giving the entire ensemble a landscape orientation. The complete WVGA (852 × 480) display has a 37-in. diagonal and is intended for SDTV applications. Rainbow technical guru J. Peter Krusius (who is also Director of the Electronic Packaging Program at Cornell University) said the company is almost ready to commercialize the 37-in. unit, and that a 720-line unit is coming soon. The company will beat PDPs on price for the SDTV panel, he said, and "will really beat them" on WXGA. Brave words, but how did the display work in practice? Actually, impressively well.

The viewing angle was close to a remarkable 180°, with good maintenance of color through nearly all of that range (see the summary of Krusius' paper later in this article). There was no edge break-up on motion, and only slight smearing. The unit was easier to watch when showing moving images than were any of the PDPs being demonstrated at the exhibition. (It should be said that, as a group, the Korean PDPs seemed to be 12–18 months behind the best Japanese PDPs in the quest to tame motion artifacts; and the Rainbow display ranks with Fujitsu's MVA and Hyundai's FFS as being among the best LCDs I've seen when it comes to showing video.)

Technical Program

The technical program was organized in two tracks over three days. The organizers orientated the program toward manufacturing (although that was flexibly applied), and two technologies (TFT-LCDs and OLEDs) were intentionally emphasized. Here are a few highlights.

FEDs Are Not Dead

Richard Tuck (Printable Field Emitters, Ltd.) and 11 co-authors led off a session on FEDs with their paper "Printed Field Emission Structures." Previous work at PFE has focused on fabricating FED structures with inks that were applied to the substrate by spin coating. The company has now developed inks that can be applied by screen printing and perform better than the spin-coated inks.

Next in the session, Prof. Yahachi Saito (Mie University) presented his paper "Carbon

Nanotubes: Preparation, Characterization, and Field Emission." Saito reviewed the various structures of carbon nanotubes, their performance, and their application to display devices. The advantages of carbon nanotubes as field emitters with sharp tips include a large aspect ratio, mechanical strength, a stable and chemically inert surface, and very low atomic mobility, he said. Saito reported the fabrication of CRT light bulbs and VFD panels in collaboration with ISE Electronics. He concluded by saying, "The future of nanotubes looks very bright and they are extremely versatile. The fundamental science and applications of nanotubes are progressing rapidly."

LCD Manufacturing

In "Manufacturing Issues in Wide-Viewing-Angle TFT-LCDs," Seung Hee Lee and Jai Wan Koh (Hyundai Electronics) described the major wide-viewing-angle LCD technologies and characterized them in terms of their relative performance and manufacturability at both the cell and array levels. Among the technologies discussed in detail were film-compensated TN, divided-domain TN, IPS and FFS, MVA, and PVA and SE (surrounding electrode).

Lee concluded the talk by reminding the audience that the yield of an old process is always better than that of new processes – at first. Each of the technologies discussed has strengths and some weaknesses – be it in a performance area, number of masks needed, or in alignment issues – and all require further development. Which mode is "best" depends on the performance and cost requirements of the particular application, said Lee, and he tastefully refrained from touting Hyundai's own FFS technology. But when I asked him in the Q&A session which technology he liked best, given the state of knowledge today, he admitted to liking fast FFS based on the combination of all features taken together, including gray-level response.

In a detailed and interesting paper, "Current and Future Technology of Low-Temperature Poly-Si TFT-LCDs," Yasuhisa Oana (Toshiba LCD Research and Development Center) said the performance of LTPS will improve substantially over the next few years, with excimer laser annealing (ELA), ion doping, and gate-oxide formation being the main contributors to the enhanced performance.

The current polysilicon TFTs will be replaced with grain-boundaryless liquid-crystal (GBLC) TFTs, which will increase the electron mobility from today's 100 to 300 cm^2/V-sec – and subsequently to 500 cm^2/V-sec. Oana said GBLC-TFT "means there are no grain boundaries in the TFT channel region, and it will be realized by using large grain-sized poly-Si film."

The next-generation design rules would go from today's 4 μm to 1 μm in the next generation and 0.5 μm subsequently. Similarly, the clock frequency would go from 2 to 100 MHz in the next generation, and then to 200 MHz.

Ken Werner

Two of the floors at Seoul's Techno-Mart were devoted to domestic (Korean) electronics. There was nothing wrong with the TV receivers. The dark bars on the screens is an artifact caused by the interaction between the vertical refresh period of the receivers and the shutter speed of the camera, which was about half a scan period.

International OLED Technology Roadmap Development Initiated in Seoul

An international effort to develop a technology roadmap for organic light-emitting displays (OLEDs) was begun at the IDMC in Seoul. The goal is to provide a forum in which researchers and potential manufacturers can collaborate with system integrators and with suppliers of materials and equipment to guide the growth of this promising new display technology. Such collaboration will be essential for any flat-panel technology that hopes to challenge the market dominance of liquid-crystal displays.

Over 60 scientists and engineers participated in this first workshop, organized jointly by the Electronic Display Industry Research Association of Korea (EDIRAK) and the U. S. Display Consortium (USDC). The study is being conducted by six working groups, each addressing separate aspects of OLED development:

1. System design, performance characterization, and marketing strategies.
2. Substrates (glass and plastic) and encapsulation.
3. Active materials: light emitters, transport layers, and electrodes.
4. Deposition and patterning.
5. Electronics: conduction lines, TFT arrays, drivers, controllers, *etc.*
6. Manufacturing strategies: fab architecture, substrate size, yield, throughput, *etc.*

The second workshop in this series will be held on January 23, 2001, in Montpelier, France. All proponents of OLED technology are invited to join in the development of this roadmap, which will be implemented primarily over the Internet. Prospective participants should send an e-mail to norman@usdc.org, indicating which group they would prefer to join.

– Norman Bardsley

Oana estimated that a mobility of 500 cm^2/V-sec would be enough to fabricate a "sheet computer – one in which the display is fully integrated with CPU, memory, image sensor, and wireless signal out/in devices" on a glass substrate.

In "Optimization of TFT-LCD and a Large-Scale Production Line for Large Glass Substrates," Kiyoshi Yoneda and his colleagues at Sanyo Electric Co. performed a productivity analysis of ELA and the other processes required to make LTPS LCDs based on investment costs for various motherglass sizes. They concluded that if various process problems can be overcome, "it will be possible to construct a large-scale production line using large glass substrates such as 3.5 or 4th generation size in the near future." It will enable LTPS TFT-LCDs to be "strongly cost-competitive against a-Si TFT-LCDs."

In "TFT-LCD for Large-Size TV Applications," Jun Hyung Souk (Samsung Electronics Co.) straightforwardly stated that before TFT-LCDs can become mainstream TV displays, significant improvements must be made in the liquid-crystal on-off and gray-to-gray response time, color gamut, and luminance – and cost must be substantially reduced. Nonetheless, the potential is tempting. Souk presented estimates of the market size for LCD TV sets over 8.4 in. on the diagonal, indicating that the market would grow from 350,000 units this year to 1.4 million in 2002, 3 million in 2003, and 6 million in 2005.

He said that even the fastest of today's wide-angle LC modes – PVA, Super V, Super-IPS, and MVA – are not fast enough for immediate TV application. "A minimum value of 15-msec gray-to-gray speed (less than one frame time) is required to eliminate image-dragging effects in motion pictures." But Souk believes this speed will be obtained this year, and a new high-speed LC mode will permit 10-msec gray-to-gray speed by 2002.

We must work toward $10 per in. technology, he said. Some current 15-in. LCDs accomplish this, but new technology is needed for larger sizes – even with forward estimating on yield.

AMLCD Manufacturing

In "Requirements for Large-Size and High-Resolution TFT-LCDs," which led off a packed session on AMLCD manufacturing, T. Ueki (IBM Japan) described the design and construction of a wide-QUXGA (3840 × 2400) TFT-LCD monitor with a 28% aperture ratio, 400:1 CR, 235-cd/m^2 luminance, and 16.6-msec response time. The dual-domain IPS panel utilizes "one-drop fill" of the cells. There are no injection holes.

C. W. Kim and his colleagues from Samsung Electronics presented the paper "Manufacturing Technologies for Next- Generation a-Si TFT-LCDs." They stated that the 14.1-in. XGA display will remain the mainline PC display through 2005, and implied that the current mainline monitor LCD (15 in.) may hold its position through 2005 or be superseded by 17- and 18-in. versions.

The conclusion that follows from these observations is that panel size has been maximized; higher pixel density is the issue. Notebook panels are going from 14.1 XGA to 15.0 UXGA, Kim said. To make the panels that will fulfill this trend, aperture ratios must go up and the number of mask layers must go down. One way to make pixels with higher aperture ratios is to fabricate the color filter on the TFT side of the liquid-crystal sandwich. There is no assembly mismatch of filter and cell, but the process is more complicated.

Kim discussed reduced-mask processes in some detail, and noted that manufacturers are thinking about Gen 5 motherglass – perhaps 1000 × 1200 mm – for higher productivity.

In "Active-Matrix Display Layout Optimization for Sub-pixel Image Rendering," Candice Brown Elliott (ClairVoyante Laboratories) observed that software – such as Microsoft's ClearType and Adobe's CoolType – cannot optimize subpixel rendering by itself. For that, one must also redesign the pixel geometry. She described ClairVoyante's proprietary design, the Pentile Matrix™, which doubles addressability and MTF in both the horizontal and vertical directions, and does so with both black-and-white and full-color images. The algorithm that remaps outputs from RGB stripe to Pentile can be implemented in software or in a small ASIC of between 5000 and 15,000 gates, she said.

J. Peter Krusius and his colleagues from Rainbow Displays and Philips FDS described the tiled display discussed in the Exhibits section of this article in the paper "Manufacturing of Large Wide-Viewing-Angle Seamless Tiled AMLCDs for Business and Consumer Applications." The companies had shown a display at SID 2000 that had 2 × 2 tiling. The next goal was to be a WVGA display with 1 × 3 tiling and only vertical seams for WVGA. Because a tiling allocation border is needed on all the pixels – not just the ones on the margin – for visually seamless tiling, tiling on only the vertical edge improves aperture ratio. Access wiring is a challenge with column and row access lines coming out of the same edge; there are quite a number of crossovers, but they are manageable, said Krusius. For production reasons, Rainbow orients the RGB stripes horizontally, *i.e.*, perpendicular to the vertical seams.

The technology is based on several elements, including a novel brightness/color-matching scheme done on the fly. When the display was demonstrated, the tiling lines were completely invisible most of the time, and only faintly visible with some image colors. Nearly 180° viewability is obtained by collimating the light from the backlight before it passes through the LCD, where it is diffused, said Krusius. Very little reflection was observed from the front surface.

Ken Werner

The shuttle bus from the Sheraton Walker Hill to Seoul's subway deposits its riders across the street from the Techno-Mart, a department store consisting of many dozens of individual shops.

SRO for OLEDs

The Thursday morning OLED session had standing room only, and there were still standees even after additional chairs were brought into the room.

Sung Tae Kim (LG Electronics Institute of Technology) discussed LG Electronics' development of an OLED display for a PCS wireless telephone in "PCS Handset with OLED Display." The instructions from LG's cellular-phone group were that the OLED had to be a plug-in replacement for the existing LCD. The project is a serious one. LG is spending $1.3 billion on development. Full graphic multicolor displays should appear in phones in a year and a half.

Kim presented the structure of the LG display, and observed that luminous efficiency is an issue. The efficiency of the red phosphor needs to be doubled; yellow is good now. Kim's group found that ac operation gives much better lifetime to half-luminance than does dc, in contradiction to conventional wisdom.

Kim thinks that there are already too many national players in the OLED game, and probably only three can make money. But there is room for smaller companies as suppliers of chemicals, plastics, sealing, chips, and equipment.

In "Polymer OLED: Display Design Aspects and Material Requirements," Ho Kyoon Chung (Samsung) observed that polymer LEDs (PLEDs) have lots of advantages over small-molecule OLEDs, but there are also challenges. One issue that is shared by PLEDs and small-molecule OLEDs is color rendition. Blue and green are not bad (on the CIE color diagram), but "red" is more like an orange-yellow, so deep reds can't be produced.

In passive-matrix PLEDs, the pixels are scanned, so peak luminescence is much greater than average luminescence. Peak green needs to be 25,000 cd/m^2 for an SVGA display, and a higher peak means lower efficiencies and higher driving voltage. Current polymer materials are already well suited to the lower voltages necessary for active-matrix operation. Chung concluded by observing that while passive-matrix PLEDs may be a good place to start, active-matrix technology needs to be developed to fully exploit the benefits of polymers.

Backlights

In "TFT-LCD Backlight Unit (BLU) Manufacturing in Korea," Tae-Hyun Choi and Cha-Yeon Kim (Taesan LCD) delivered a wide-ranging talk on technological and commercial considerations. They noted that the backlight unit accounts for half of an LCD module's panel thickness and a major part of its power consumption. The dominant lamp in backlights is the cold-cathode fluorescent lamp (CCFL). These lamps are quite efficient, but only about 30% of their light enters the backlight's lightguide pipe (LGP). We need new designs and new materials, said the authors. Will the next generation be a flat lamp? The next LGP will be both printless and patternless, they said.

Taesan is proud of their low failure rate, which is 6568 per million panels. This compares to 11,074 per million panels for Japanese makers and 12,896 per million for all Korean makers. Taesan is hoping to drop its failure rate from the current 0.66% to less than 0.5% soon. Taesan sees a backlight-unit market growth of about 30% per year for the next several years.

Conclusion

This first IDMC was widely held to be a critical success, with many stimulating papers, and FPD Expo Korea contributed to this success with a very good trade show. IDMC Secretary General Sungkyoo Kim said that the conference was also a financial success.

The organizers intend to make IDMC a regular event, but they are discussing the possibility of moving it from September to January, which is a less crowded part of the display conference season. ■

Circle no. 16

Circle no. 17

Introducing the world's most advanced FED technology in a high-volume cluster tool.

The new Temescal® FCE-7000 from BOC Coating Technology is very big news: In fact, if you're looking for high-volume FED flat panel deposition with lowest cost of ownership and incredible flexibility, it just doesn't get much better than this...

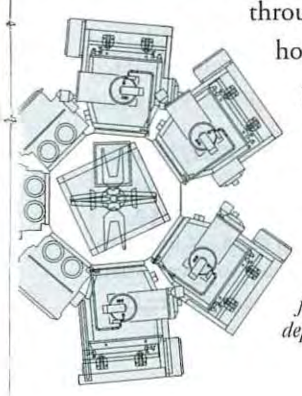
To start with, there's BOC's world-class e-beam technology – which gives you the best uniformity, highest rates, longest life and largest source inventory, to cite just a few of its merits.

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.

Plus, your panel size choices are virtually unlimited. The tool now handles up to 600mm x 720mm, which happens to be the largest in the world. But BOC can also configure it for even larger sizes upon request.

Highest throughput. Lowest cost of ownership.

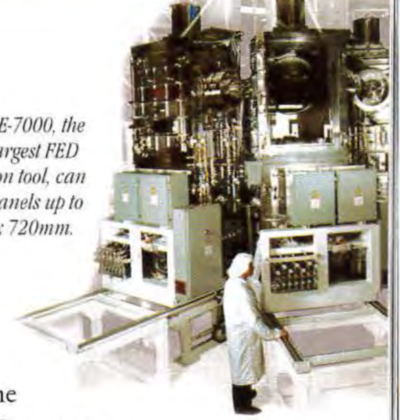
The FCE-7000 is a proven production tool that generates throughput speeds of from 10 to 60 panels per hour – and even up to 70 and 75 on certain processes. And when you combine that kind of throughput with high production quality levels, you get a very attractive return on your investment.



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

And this system also reduces downtime and requires less maintenance.

Plus, it provides more advanced automation and higher materials utilization. So you can see how it achieves the lowest cost of ownership of any flat panel deposition system in the industry.



BOC's FCE-7000, the world's largest FED production tool, can process panels up to 600mm x 720mm.

A full spectrum of solutions.

BOC has been producing coating systems for more than 35 years now.

So they can provide not only high-throughput production systems, but also prototype R&D and intermediate systems, as well.

They can also provide you with an unmatched repertoire of process and system knowledge and managed engineering expertise.

So, even if your process is not yet fully developed, you can depend on BOC to help you answer the questions, negotiate the risks and get where you want to go.

Bottom line, it means smarter solutions – from the big performance guys, BOC. Call them and see for yourself...

Temescal, a part of BOC Coating Technology, 2700 Maxwell Way, Fairfield, CA 94585. (707) 423-2100. Fax: (707) 425-6071.

BOC
COATING
TECHNOLOGY

Circle no. 20

continued from page 4

furniture items such as beds and sofas, and houses with vehicles. Even the simplest of combinations – such as a television with a VCR – has had only limited success.

Now, before you get all excited and call to tell me about the sofa-bed industry, the recreational-vehicle industry, the mobile-home industry, and the great houseboat and clock radio that you own, let me state that I am not suggesting that these do not exist as viable products. What I am suggesting is that they have in no way replaced the products that provide these functions in their pure form. In the same way that the proverbial Swiss Army knife can be a useful device in special circumstances, while not replacing the tools that perform each of these functions, a sofa bed is useful in a one-room apartment or a guest room, a recreational vehicle is great for those who wish to spend their retirement years traveling around the country, and the houseboat is great if you want to be intimate with a body of water. However, for most of us, these are not the preferred ways of performing the functions for which we buy sofas, beds, houses, and cars. The mainstream products thrive while the specialty products serve a much smaller – although still important – segment of the market. So, when I am told of the plans by some companies to bring about the convergence of television and the Internet, and how we will all be glued to our TV sets doing e-mail, interactive shopping, and searching for information, I tend to be a skeptic. While I can see a few people doing it, for most of us I don't think it will be that interesting.

First there is a practical viewability problem. Sitting in front of a computer to watch television doesn't seem all that comfortable. On the other hand, reading e-mails from two or three meters' distance – the typical television watching position – seems even more difficult. At best, I can read a dozen lines of text on my television from this distance. If I must move closer, then I can just as easily go sit in front of my computer. Furthermore, given that watching television is an activity that often involves more than one person, will this social pattern carry over to reading e-mails or searching Internet sites? Not very likely.

Finally, when I am watching television, I am usually looking for a way to forget about work-related tasks. The last thing I want is for the latest e-mail to show up on my television set. Even the possibility that I could do this makes me want to run away to some deserted island.

The personal computer has already become much like the Swiss Army knife. It does many things – but perhaps not as well as a specialized device could do them. If I want to take care of my e-mails, I want to have instant access, to be able to do it from anywhere at anytime, and I want a device that is light-weight and easy to take on my travels. If I am in my car, I want a navigation device that will tell me how to get to a particular location. If I wish to put my presentation material on a computer, it should not take me five minutes to bring up my presentation while the audience examines the contents of my files.

Desktop and laptop computers have been great products and will continue to serve us with their broad-ranging capabilities. However, I believe there is great opportunity for products that do specialized functions exceedingly well. Many of these products will be highly portable and will need displays that are efficient and bright. Others will be used in multiple locations in homes and offices and will need low-cost displays that still provide color and excellent resolution. Yet others will be used in conference settings and will need to display clear images on large screens readable in normal room ambience.

Divergence is going to be great for those of us in the display industry. It will allow us to be creative in bringing many new display technologies to market. It will demand that we work closely with product designers and that we understand the specialized needs of our customers. The only temporary detractors from this inevitable trend will be the few dominant companies that would prefer to retain control over the Information Society with their limited offerings of Swiss-Army-knife-like products.

Since I have always liked lots of choices, I am an enthusiastic proponent of these opportunities and am looking forward to helping bring about some of this diversity.

Should you wish to provide some of your own – perhaps divergent – thoughts, you may reach me by e-mail at silzars@attglobal.net or at president@sid.org, by telephone at 425/557-8850, by fax at 425/557-8983, or by the pre-divergent method known as the U.S. mail at 22513 S. E. 47th Place, Issaquah, WA 98029.

Aris Silzars is President of SID and lives on a hilltop in Issaquah, WA. ■

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.

Circle no. 23

Circle no. 24

Circle no. 25

Circle no. 26

Circle no. 27

Circle no. 28

Circle no. 29

editorial

continued from page 2

This issue features a special report on the first International Display Manufacturing Conference, held in September.

– KIW

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

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.

calendar

The Sixth International Conference on the Science and Technology of Display Phosphors. Sponsored by DARPA and SID. Contact: Mark Goldfarb, Palisades Institute for Research Services; 212/460-8090 x202, fax -5460, e-mail: mgoldfar@newyork.palisades.org.
Nov. 6–8, 2000 San Diego, CA

Eighth Color Imaging Conference: Color Science, Engineering Systems & Applications. Sponsored by IS&T and SID. Contact: Dee Dumont, SID HQ, 408/977-1013, fax -1531, e-mail: office@sid.org.
Nov. 7-10, 2000 Scottsdale, AZ

COMDEX Fall 2000. Contact: Key3Media Events; 781/433-1500 or 650/578-6900.
Nov. 13-17, 2000 Las Vegas, NV

Electronic Information Displays (EID 2000). Sponsored by SID. Contact: Trident Exhibitions, +44-(0)-1882-614671, fax -614818, e-mail: info@trident exhibitions.co.uk.
Nov. 21-23, 2000 London, UK

The Seventh International Display Workshops (IDW '00). Sponsored by ITE and SID. Contact: IDW '00 Secretariat; +81-3-3423-4180, fax -4108.
Nov. 29–Dec. 1, 2000 Kobe, Japan

10th International Workshop on Inorganic and Organic Electroluminescence (EL '00). Contact: Prof. Y. Nakanishi, Workshop Secretary, +81-53-478-1346 (fax), e-mail: nakanishi@rie.shizuoka.ac.jp.
Dec. 4–7, 2000 Hamamatsu, Japan

2000 International Electron Devices Meeting (IEDM). Contact: Phyllis Mahoney; 301/527-0900 x103, fax -0994, e-mail: phyllism@widerkehr.com
Dec. 11–13, 2000 San Francisco, CA

The 17th Annual Flat Information Displays Conference. Sponsored by Stanford Resources. Contact: Laura Barretto at 408/360-8400, e-mail: sales@stanfordresources.com.
Dec. 12–14, 2000 Monterey, CA

Consumer Electronics Show 2001. Contact: Consumer Electronics Association; 703/907-7605, fax -7675, e-mail: cesinfo@ce.org.
Jan. 6–9, 2001 Las Vegas, NV

2001 SID International Symposium, Seminar & Exhibition. Sponsored by SID. Contact: SID Headquarters, 408/977-1013, fax -1531, e-mail: office@sid.org.
June 3–8, 2001 San Jose, CA ■

Helmet-Mounted Displays: Design Issues for Rotary-Wing Aircraft

Clarence E. Rash (ed.), U.S. GPO 1999-735-164, 1999, 293 pages.

Reviewed by Kenneth E. Sola

For anyone interested in the history and evolution of Army helmet-mounted displays (HMDs), this little book is all one needs. Clarence Rash has pulled together Army experts and addressed the key areas in HMDs for helicopters.

The text is palatably understandable and richly supplemented with figures, formulae, and photographs. It will also be comforting to most readers to know that one will not be burdened by a crush of military acronyms.

Dr. Rash lists the design issues early:

> Virtually every HMD, concept or fielded system, suffers from one or more deficiencies, such as [heavy] head-supported weight, center-of-mass (CM) offsets, inadequate exit pupil, limited FOV, low brightness, low contrast, limited resolution, fitting problems, and low user acceptance.

And these are only a few of the problems inherent in fitting a display directly onto the head of an aviator to assist in piloting and targeting tasks.

Although the HMD problems, and their interaction, seem insurmountable, the book offers a very positive research trail of problems addressed and resolved. For the current researcher in the HMD field and the young engineer interested in making a career contribution in this critical area, this book offers hope and a focus on most of the persistent problems remaining to be solved.

Perhaps the greatest value of this book is its extensive reference list which, while concentrating mostly on Army researchers, manages to cite most of the best in vision research (*e.g.*, Boff & Lincoln, Farrell & Booth, Hart, Infante, Silverstein, Snyder, and Yaniv).

Rash establishes the framework early: (1) image sources [displays], (2) display optics, (3) helmet, and (4) tracker. Thereafter, he and his colleagues address these issues in chapters on displays, optical designs, visual coupling, optical and acoustical performance, and biodynamics. These are the best sections, especially those where Dr. Bill McLean, an Army research optometrist, brings mathematical rigor into the discussion.

Rash wisely limits the scope to HMD hardware design issues. He doesn't tackle imagery content (*e.g.*, data, symbology, formatting), and states early on that this " ... is not a cookbook for building an integrated helmet and display system."

Perhaps of greatest interest to readers of *Information Display* are the chapters on image sources [displays] and optical performance. Though the book is copyrighted 1999, most of the discussion concerns CRTs. In fact, all of the fielded HMDs currently use CRTs. Flat-panel technology is addressed, but the discussion is somewhat stale, considering recent improvements in technology in the area of FPDs. In the image-sources chapter, field-emission displays (FEDs) are described as "the most promising display technology" to replace CRTs and cited as "the holy grail of image sources." There is market potential in supplying lighter, more effective displays to meet military HMD requirements.

I must warn those who – like me – are specifically interested in the human-factors engineering of HMDs that this book is of limited interest. Chapter 9 (HFE Issues) and Chapter 10 (Test & Evaluation) merely tell one what to look for and how to look for it. Saved as the final chapters in the book, they total 23 pages and leave the reader wondering, "Is that all there is?"

This disappointment is acute, since in his excellent introductory section, Dr. Rash prepares us for some significant HFE discussion. For instance, when he cites "low user acceptance" as one of the HMD deficiencies, and goes even further in stating, "Of the potential problems with HMDs, none are more troublesome than those associated with the interfacing of the system with the human user." He also lists 21 different and conflicting requirements for HMDs – but user acceptance is not mentioned in the list.

Thus, the hardware of HMDs is well covered in this book, but the human "software" – the aviator's brain – is not adequately addressed. Readers will have to go elsewhere to find the details concerning what aviators really think about flying HMDs.

***Kenneth E. Sola** is an engineering psychologist in the Crew-Systems Engineering Division at the Naval Air Warfare Center, Aircraft Division (NAWCAD), Patuxent River, MD; telephone 301/342-9261, fax 301/342-9305, e-mail: SolaKE@navair.navy.mil.*

Projection Displays

Edward H. Stupp and Matthew S. Brennesholtz (eds.), Wiley–SID Series in Display Technology, John Wiley & Sons, in Association with SID, 430 pages.

Reviewed by Terry Schmidt

This is a brilliant and practical collection of useful information, principles, and concepts used in modern electronic projection systems of all types. The text is straightforward and easy to read, making it easy to understand even difficult principles. It uses minimal mathematics, yet enough formulae, data, and references are presented to be useful as a reference text. This is certainly a feat for a technical treatise, much less one spanning as many varied disciplines as *Projection Displays*.

The 430-page book, published by John Wiley & Sons in association with SID, is broken into five logical components to facilitate quick reference. In Part 1, the authors, each bringing 20 years of experience to the reader, begin with a fresh overview of an electronic projection market that didn't even exist a few years ago. Categories ranging from portable presentations to electronic cinema are studied in terms of their customer requirements and the technologies best suited to meet their specific needs. In this introduction, the reader is familiarized with key projection performance issues such as brightness, contrast, and image resolution. The authors also state up front that traditional overhead projectors, and the electronics, outside of the displays themselves, are not covered.

Part 2 examines, in detail, key image-forming components. These range from technologies that emit their own light, such as traditional projection CRTs and newer laser-powered systems, to light valves that control illumination from a lamp, such as liquid crystals, and microelectromechanical devices. Principles of operation are described with the assistance of charts, graphs, and a generous number of layout diagrams. Important performance details are explained that will assist designers to know when a projection system is optimized or when to dig deeper.

Part 3 explains key optical components,

such as thin-film dichroic filters, as well as UV, IR, and anti-reflection coatings. Recent advances in polarization recovery techniques are described, including the pros and cons of various layouts. Projection-lens "offset" is well explained as the cure for keystone distortion for projection above the optical axis in flat panels. This section dedicates over 100 pages to details that educates and encourages us all to innovate and discover new designs to further optimize the state of the art.

Part 4 is suitably named "Projector Architectures and Performance." In this section, both three-lens and single-lens CRT systems are described in terms of their advantages and disadvantages. The long history, lower cost, and analog simplicity, along with the excellent image quality, continue to make the CRT projection category significant and important even today. Reading between the lines, however, one can see that this technology will soon be squeezed out as costs come down and resolution and image quality improve on newer flat-panel projectors. Important three-panel topologies, as well as one- and two-panel systems, are described, and detailed diagrams of the optical layouts are included. The authors are fair in their praise and criticism of the various good and bad features of each system. The text brings to light often hidden details, such as alignment difficulties or low efficiency, which may rule out an otherwise great optical-layout candidate.

Part 5 is an often overlooked but absolutely key part of any projection product: "Display Characterization and Perception." Perception may be the only thing that differentiates a product from the competition. In this section, the authors describe the human visual system and how spatial and temporal characteristics, luminance, contrast, and color all play together to form an image that leaves a favorable perception. Essential ANSI contrast and luminance measurement procedures are fully described, including test patterns. Image artifacts, or items detracting from a perfect image, such as moiré, pixelization, flicker, and judder, are also explained in detail.

The book is finished off with a flourish of appendices that act as references for radiometric and photometric terms and definitions. The perplexing "optical invariant," or étendue concept, is allocated 11 pages of excellent text and diagrams to illustrate its detrimental effect on lumen output from lamp-based projector systems. Finally, a glossary of terms completes a valuable reference work well worth having constantly near at hand.

Terry Schmidt is an Advanced Development Engineer at Christie Digital Systems in Kitchener, Ontario, Canada, and is currently the Director of the Canada Chapter of SID. ■

sustaining members

Acer Display Technology
Ad-Vance Magnetics, Inc.
Advance Reproduction Corp.
Agilent Technologies
American Panel Corp.
AMJ Industries, L.L.C.
Applied Concepts, Inc.
Applied Films Corp.
Artesyn Solutions, Inc.
Aurora Systems
autronic – Melchers GmbH

BPS
Babcock, Inc.
Blue Fin Technologies
BOC Coating Technology
Brimar Ltd.
Brown & Sharpe Surface Inspection Systems, Inc.

Candescent Technologies
Canon, Inc.
CELCO
The Cherry Corporation
Chunghwa Picture Tubes, Ltd.
Clinton Electronics Corp.
Colorado Microdisplay, Inc.
Compaq Computer Corp.
Corning Incorporated
Corning Japan K.K.
Crystaloid Technologies
CYRO Industries

DigiLens, Inc.
Digital View, Inc.
Display Laboratories, Inc.
DisplaySearch
Dontech, Inc.

Earth Computer Technologies
ELDEC Corp.
Electro-Plasma, Inc.
eMagin Corp.
Emco Electronics Ltd.
Endicott Research Group, Inc.
ERSO/ITRI

F-P Electronics
Fresnel Optics
Futaba Corp. R&D Center

Gerome Manufacturing Co., Inc.
Graphico Edgelit Panels

Hannstar
Hitachi, Ltd.
Honeywell
Hoya Corporation USA
Hunet, Inc.

IBM
iFire Technologies
Imaging & Sensing Technology
Imaging Systems Technology
IMT Masken und Teilungen AG
Incom, Inc.
Industrial Electronic Engineers, Inc.
Infinite Graphics, Inc.
Innova Electronics, Inc.
Instrument Systems
Interface Display & Controls, Inc.
Interserv Corp.
Intevac, Inc.
InViso
Ion Systems
Ise Electronics Corp.

Kent Displays

LCD Lighting
LC-Tec, Inc.
Lexel Imaging Systems, Inc.
Lite Array, Inc.
Lumin-Oz, LLC

Micronic Laser Systems AB
Microsemi Corp.
Microvision Corp.
Minolta Corp.
Mitsubishi Electric Corp.
Mitsubishi Electronics America
Molex, Inc.
Motorola Telematics Computer Group

NEC Corp.
Nippon Seiki Co., Ltd.

OCLI — A JDS Uniphase Company
OES/ITRI
OKI Electric Industry Co., Ltd.
Optoma Corp.
Optrex America, Inc.

Philips Flat Display Systems
Phosphor Technology Ltd.
Photon Dynamics
Photo Research
Pilkington Micronics Ltd.
Pioneer New Media Technologies
Planar Systems
Plasmaco, Inc.
Polar Vision, Inc.
Polytronix, Inc.
Premium Allied Tool

Quanta Display, Inc.
Quantum Data Inc.

Rexam Image Products
ROLIC Research Ltd.

Sarnoff Corp.
Schott Corp.
Sharp Corp.
SI Diamond Technology
Silver Cloud Manufacturing
SmartASIC
Sony Chemicals Corp. of America
Sony Corp. Research Center
Stanford Resources, Inc.
Superior MicroPowders
Supertex, Inc.
Symbol Technologies, Inc.
Syntronic Instruments, Inc.

Tamarack Scientific
TCO Development
TDK Corp.
TEAM Systems
Techneglas, Inc.
Terapixel, Inc.
Thin Film Devices, Inc.
Thomas Electronics, Inc.
Thomson Components & Tubes
Three-Five Systems, Inc.
Torrey Pines Research
Toshiba America Electronic Components, Inc.

Ultra Electronics Command & Control Systems
ULVAC Technologies, Inc.
UNIGRAF
Unipac Optoelectronics Corp.
Universal Display Corp.
Ushio America, Inc.

Video Electronics Standards Association
Viratec Thin Films Inc.

Westar Corp.
White Electronic Designs, Inc.
WINTEK Corp.

index to advertisers

Business and Editorial Offices
Palisades Institute for Research Services, Inc.
411 Lafayette Street, 2nd Floor
New York, NY 10003
Jay Morreale, Managing Editor
212/460-8090 x212 Fax: 212/460-5460
jmorreal@newyork.palisades.org

European Sales Office
George Isaacs
12 Park View Court
The Paddock, Eaton Ford
St. Neots, Cambridgeshire
PE19 7SD U.K.
Phone/Fax: +44-(0)-1480-218400
george@gandg.demon.co.uk

Sales Office
Palisades Institute for Research Services, Inc.
411 Lafayette Street, 2nd Floor
New York, NY 10003
Tracy Leibowitz, Director of Sales
212/460-8090 x211 Fax: 212/460-5460
tleibowitz@newyork.palisades.org

Korean Sales Office
Jung-Won Suh
Sinsegi Media, Inc.
Masters Tower, Room 2410
553, Dowha-dong
Mapo-ku, Seoul 121-040 Korea
+82-2-313-1951/2 Fax: +82-2-312-7335
sinsegie@chollian.net


TFT LCD Displays
1,000 nits
1,000 nits
1,000 nits