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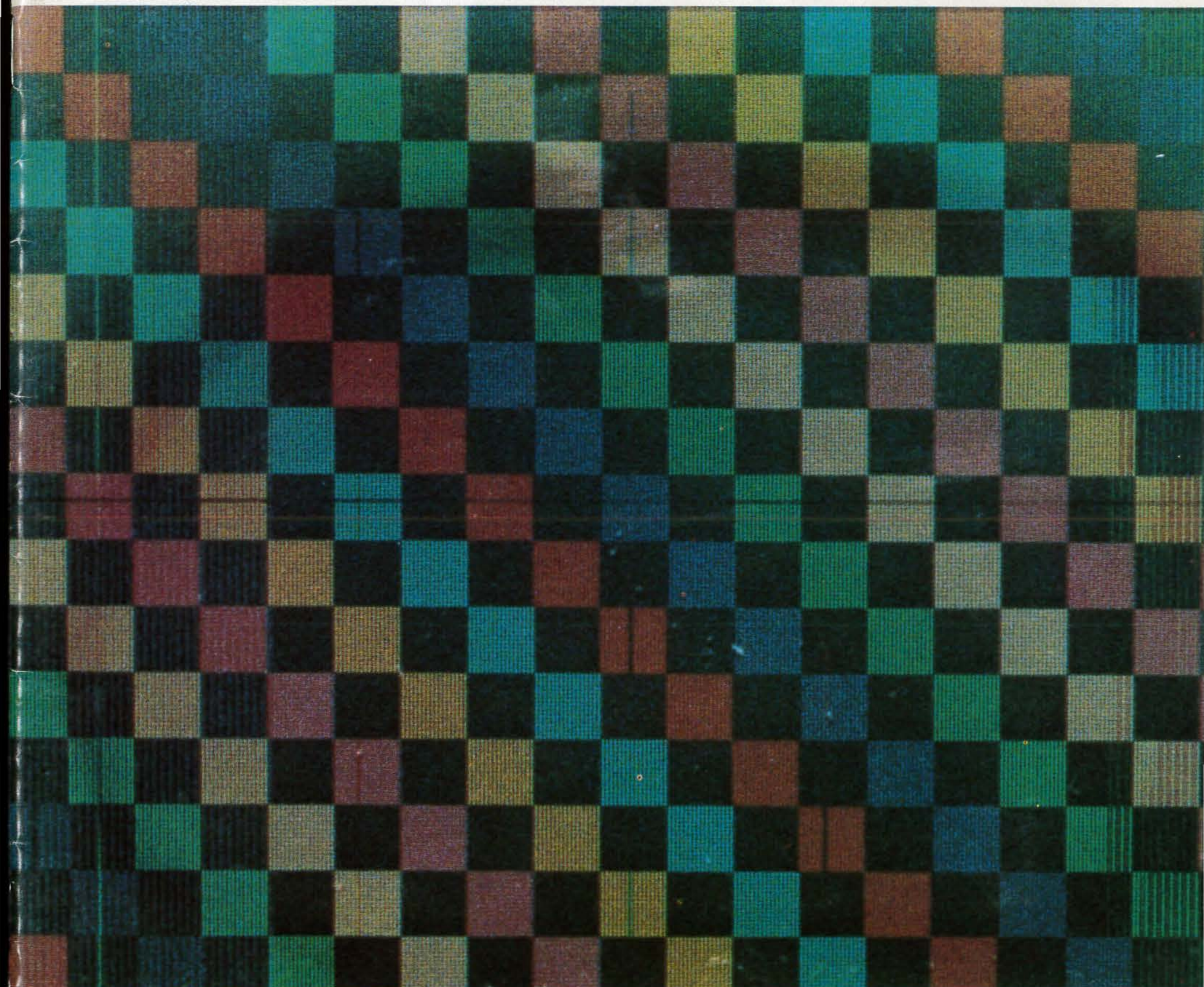
INFORMATION DISPLAY

July/August 1988
Vol. 4, No. 7&8



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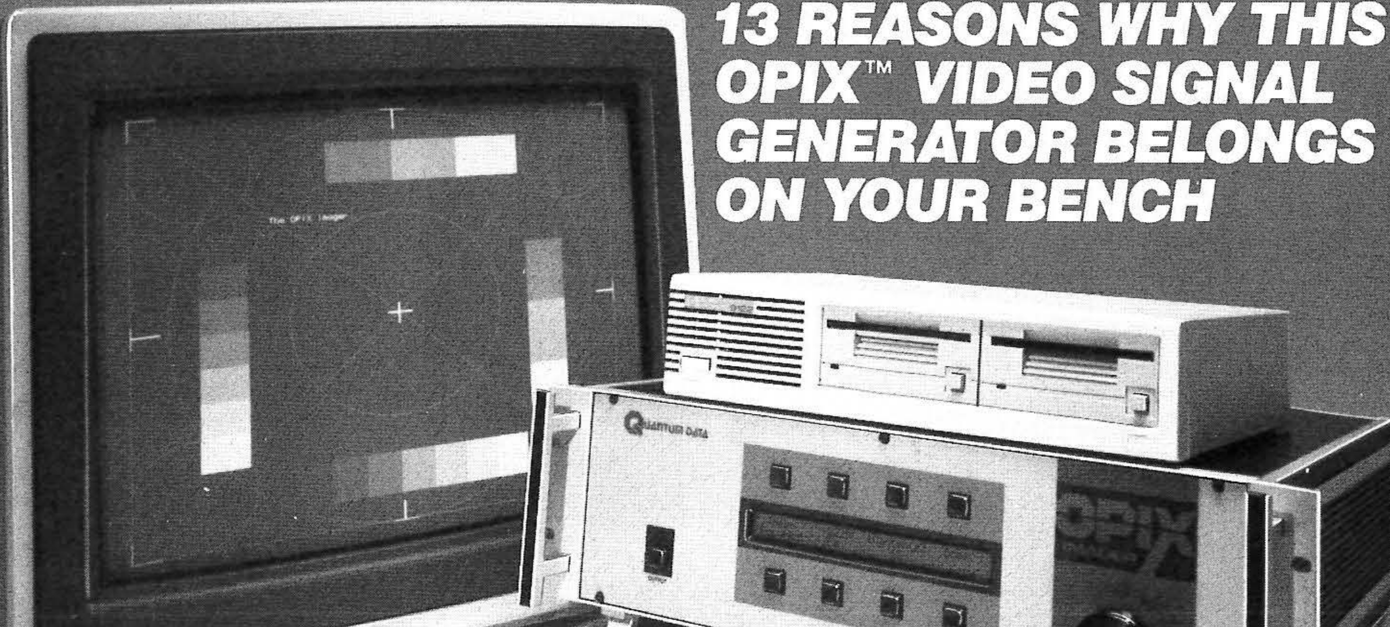

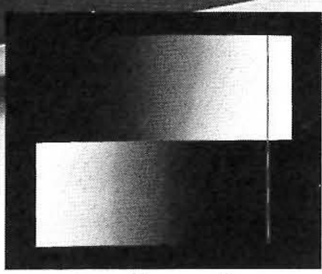

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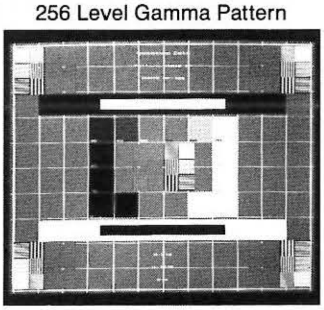

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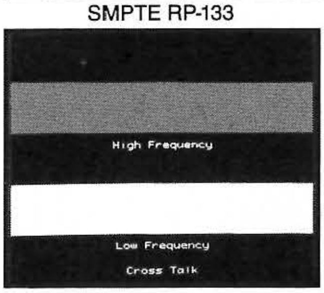

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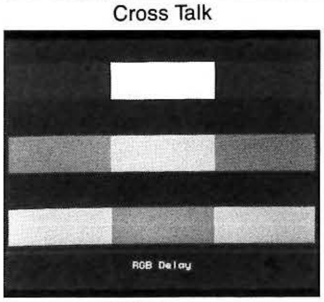

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INFORMATION DISPLAY

JULY & AUGUST 1988
VOL. 4, NO. 7&8

Cover: This full-color TFEL display was first demonstrated at SID '88 in Anaheim. It has a 6-in. diagonal and a pixel pitch of 200 lines/in. The phosphor dots are applied in linear triads resulting in a one-third pixel resolution. *(page 10)*

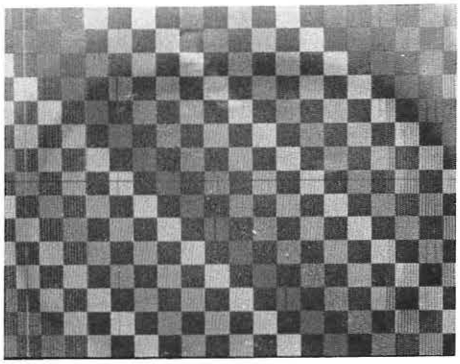

Photo: Planar Systems, Inc.

Next Month in Information Display

Industry Directory Issue

- Industry directory
- Mil-spec shadow-mask tubes
- Laser repair of LCDs

Official Monthly Publication of the Society for Information Display

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editorial

Flatlanders

This is the issue of *Information Display* we promised would be devoted to emissive flat-panel displays, and so it is. There are currently two emissive flat-panel display technologies of major commercial importance: plasma and thin-film electroluminescent.

Though both trail far behind the non-emissive liquid-crystal displays in the flat-panel derby, plasma is the dominant technology of the two. A half-million plasma displays are projected to be sold this year, many of them dc displays incorporated into Toshiba laptop and Compaq transportable computers. A smaller number of ac displays appear, for example, in GRiD laptop computers.

A far, far smaller number of TFEL displays will be sold into a variety of applications. Some of them will be incorporated into a version of the Data General DG/1 laptop computer, and others will appear in any new production of the GRiD Compass computer, an older model favored by proverbial "government purchasers" for its ability to operate after being dropped out of helicopters.

There are those who believe that the recent surge in plasma sales is a prelude to plasma dominance of the flat-panel market, with liquid-crystal displays being relegated to "low-cost-at-any-price" applications. Others feel that TFEL has now, from the technological and cost/benefit points of view at least, overcome plasma's early lead. They believe that plasma has peaked, and that new models of systems that now use plasma will increasingly switch to electroluminescent.

Elliott Schlam and Shigeo Mikoshiba generously complied with *ID's* requests to write articles on EL and plasma displays, respectively, that survey the basic technologies and recent developments. Each of these gentlemen is a strong and well-known proponent of the technology he champions.

Ric Corless, the author of our third article, makes high-precision masks used in the manufacture of flat-panel displays. He reviews the new mask-making technologies and the increased size and resolution options they provide to display makers.

This is our combined July–August issue, which gives us a chance to catch our collective breath and put the final coat of polish on our editorial calendar for 1989. The reader response cards you have been returning in increasing numbers have, in general, been highly complimentary of the direction *ID* has been taking. We hope to please you even more starting in September, with our new industry directory, continuing coverage of essential topics, and some coverage of the new and offbeat.

—Kenneth I. Werner

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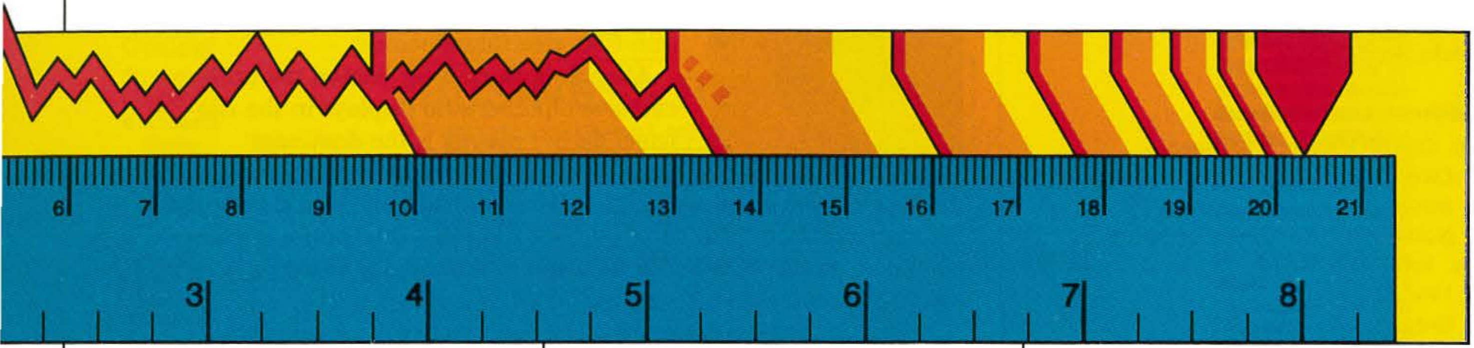

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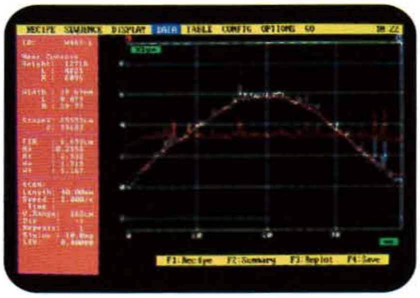

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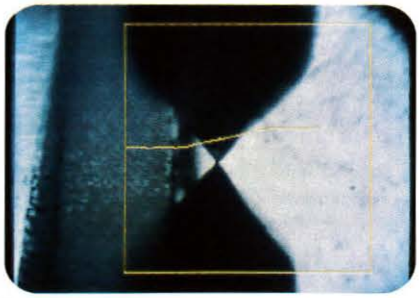

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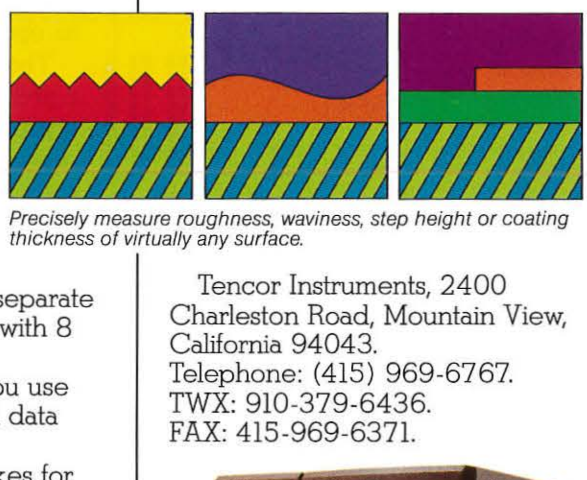

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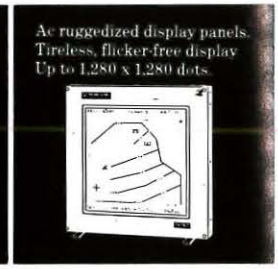

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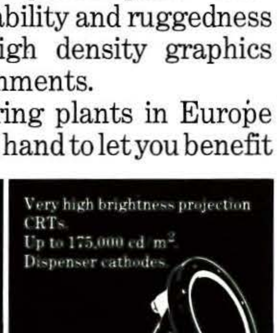

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Circle no. 7

Thin-film electroluminescent displays

BY ELLIOTT SCHLAM

THIN-FILM electroluminescent (TFEL) displays—though far outdistanced in dollar sales by plasma and liquid-crystal displays (LCDs)—are poised for major growth in most display markets. This market growth will be fueled by the instrinsic aesthetic appeal of TFEL displays, their extreme ruggedness and favorable operational characteristics, and the demonstrated ability to mass-produce TFEL display panels with a variety of production techniques. In addition, laboratory developments promise further improvements in luminance, resolution, size, and color.

The two dominant flat-panel technologies are now seriously competing with the CRT to capture part of its \$6-billion-dollar market. While they both offer certain substantial advantages over the CRT, it is well recognized that only the TFEL display offers an image crispness that is comparable (and in certain cases superior) to that of the CRT. With almost all of TFEL's technological hurdles now overcome, the remaining issues are primarily multiple-source availability and competitive pricing. The variety of TFEL production techniques that has now been demonstrated and the increased activity of driver manufacturers signal a major easing of these issues.

Elliott Schlam is vice president of marketing/sales and director of product development at Sigmatron Nova, Inc., Eatontown, New Jersey. He was previously director of the Integrated Device Processing and Displays Division of the Electronic Technology and Devices Laboratory, U.S. Army LABCOM, Fort Monmouth, New Jersey, where his work included all aspects of electroluminescent and other flat-panel displays, as well as terminal development and man-machine interface techniques. Dr. Schlam received his Ph.D., M.S.E.E., and B.E.E. degrees from New York University.

A solid solid-state display

The TFEL display panel is a sandwich structure consisting of metallic rear electrodes and transparent front electrodes and a inner dielectric on either side of a polycrystalline phosphor layer that is the light emitter [Fig. 1]. Each of these layers figures prominently in the display's operating characteristics and manufacturability.

The display is refreshed like a CRT and multiplexed a row at a time. Because the pixels in each row require a certain minimum dwell time (typically 20 μsec), the number of rows in the display determines the minimum frame time. The display is an ac device, emitting light whenever a pulse wider than the minimum pulse width and of sufficient voltage is impressed across a pixel. A consequence of this is that the luminance of a display with given dielectric and phosphor layers is controlled only by the drive voltage and refresh rate [Fig. 2]. The very sharp threshold in the luminance-vs.-voltage characteristic permits simple multiplexing of up to 500 lines or more.

Luminance at 60 Hz is typically specified as 20–25 fL—bright enough for a vivid looking display in most office and industrial applications. But for most military and some industrial applications, higher luminance is required. This can be had now by operating at higher refresh rates, but the number of rows in the display does set an upper limit.

The appearance of a TFEL display benefits from its flat surface, which cuts glare dramatically compared to conventional CRTs. (The curved CRT surface acts as a geometrical "collector" of ambient light sources such as overhead fluorescent lights and windows, and tends to direct them into the viewers' eyes.) In addition, the near-specular emission of the TFEL display invites the use of a circular-polarizing filter to realize a major contrast improvement.

Exorcising the latent image

The only nagging issue that had marred the appearance of TFEL displays was a latent image that would appear on TFEL screens as if a picture had been "burned in." Until recently, displays were driven with an asymmetrical wavetrain that consisted of a row-sequential drive pulse of one polarity and a frame-sequential refresh pulse of the opposite polarity. This resulted in a small net dc field on the display, which caused the latent image. The problem has been solved with a symmetric drive scheme that replaces the refresh pulse with a frame-sequential train of drive pulses that are alternately positive- and negative-going. This produces an average voltage across the screen that is approximately zero. The internal charge buildup that seems to be the main cause of the latent image is thereby eliminated. But there's a price for everything. For displays, such as an RS-170 monitor, that are driven with a

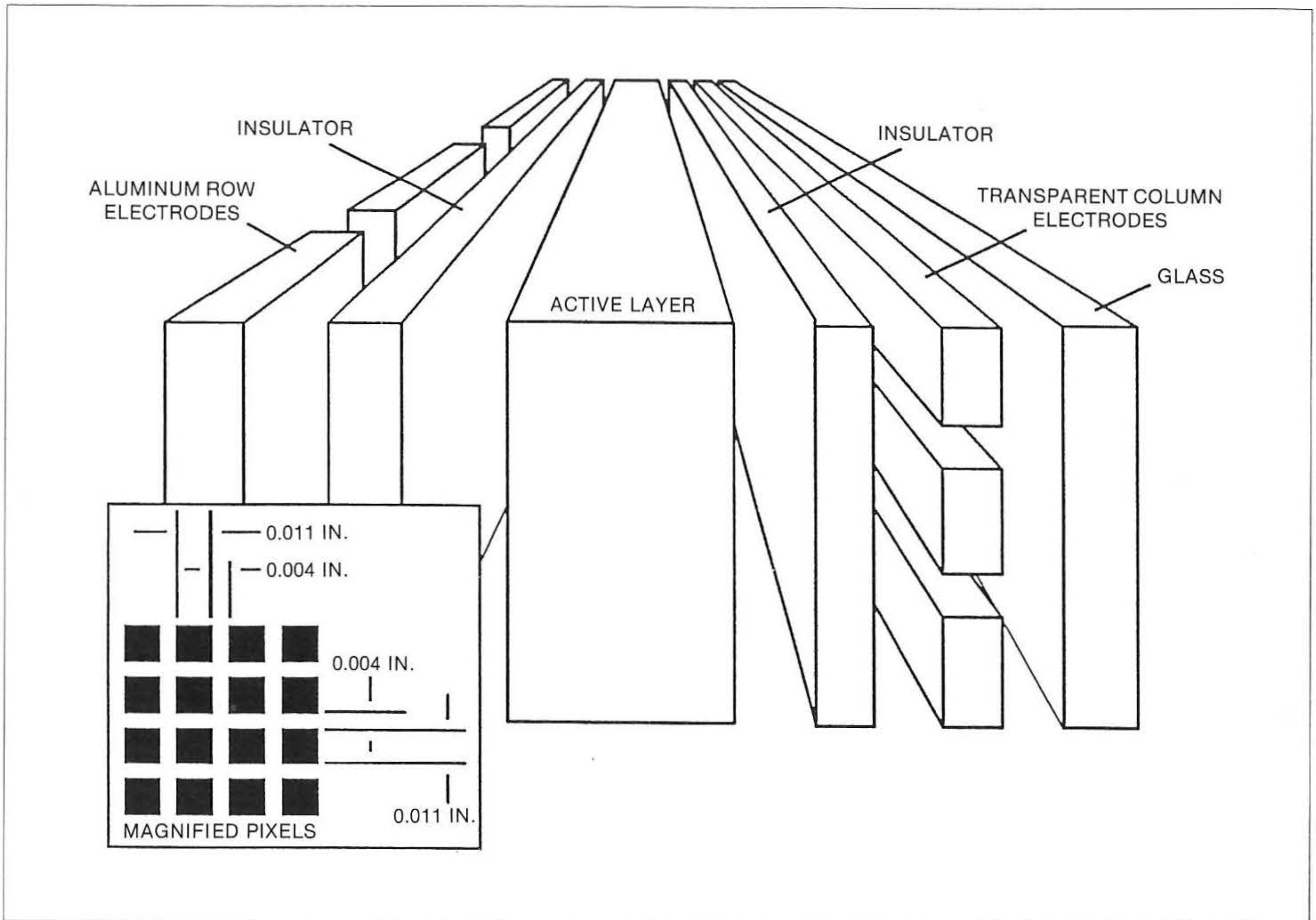


Photo: Sigmatron Nova

Fig. 1: Thin-film electroluminescent (TFEL) displays are thin, entirely solid, and fabricated on a single glass panel. The result is a remarkably rugged and easily fabricated display.

fixed refresh signal, this technique effectively reduces the display repetition rate—and the luminance—by a factor of 2. The luminance is recovered by operating the display at a higher voltage.

From an interesting mechanism, interesting features

The main excitation mechanism of the TFEL phosphor is electron tunneling from phosphor-dielectric interface states into the phosphor's conduction band. This mechanism is nearly temperature independent, so TFEL display panels operate in a wide temperature range (−55°C to + 125°C) with only gradual changes in luminance (from brighter at the cold end to dimmer at the warm end). Corrective drive circuitry can compensate for these variations. TFEL displays that are specified for operation in a narrower temperature range are limited by their auxiliary circuitry, not by the TFEL panel itself.

Power consumption of a TFEL display varies with the number of pixels excited. With asymmetric drive, the power peaks at approximately 50% pixel usage, but the power consumption is linear with pixel usage for symmetric drive. Sigmatron Nova's 3×5 in., 192 × 320 pixel display, for example, consumes approximately 10 W with all of its pixels on. However, with the screen fully loaded with 5 × 7 font alphanumeric characters (24 rows of 53 for a total of 1272 characters), total power consumption is approximately 4.5 W. With a graphics pattern, pixel usage and power consumption are less [Fig. 3]. For system designers, this power compares very favorably with that needed to backlight and heat liquid-crystal displays.

Fast + gray = TV

TFEL displays have the speed and gray scale to show television imagery. There is sufficient dynamic range before the "knee" in the luminance-vs.-voltage response curve to modulate the drive voltage with up to 16 effective luminance levels. This has been demonstrated with first-generation voltage-modulation column-driver chips from Supertex of Sunnyvale, California. Second-generation devices from Supertex and other vendors are expected shortly.

A uniform voltage response over the entire panel area is important for video products. TFEL panels typically offer a variation of 30% or less. This compares favorably with CRTs, and the human eye readily forgives gradual variations of this magnitude. TFEL's 1-msec response time is fast enough to avoid detrimental smear effects. This is not the case with liquid-crystal displays, which have responses in the 20–30-msec range at room temperature and are considerably slower at lower temperatures.

A manufacturable technology

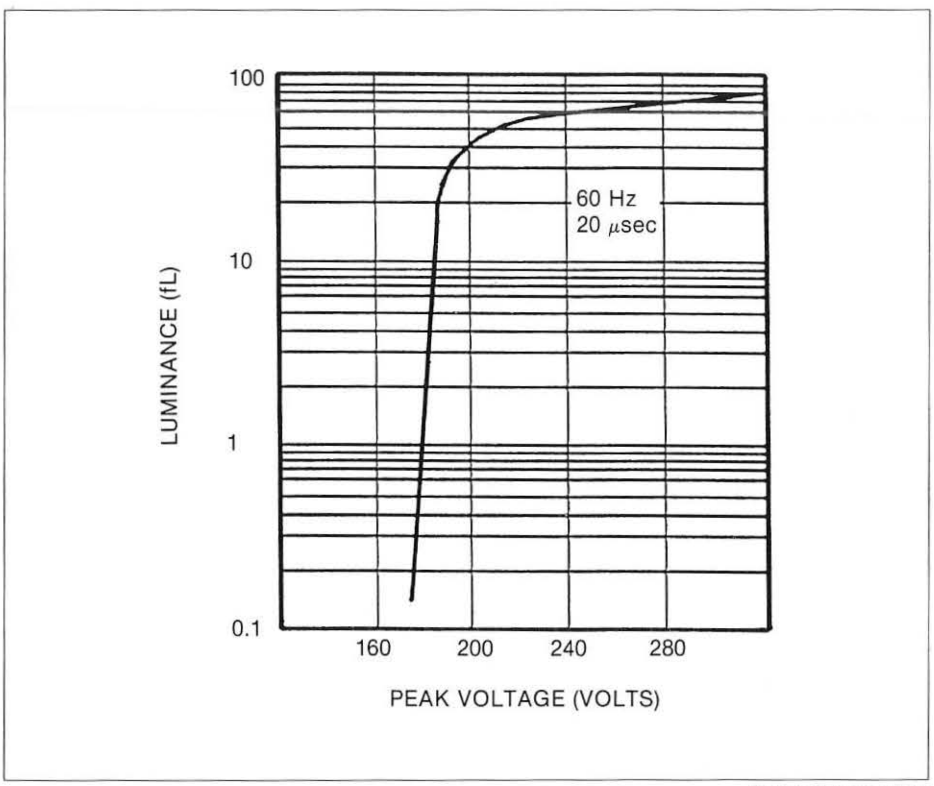
A TFEL display module consists of the display panel, driver, and logic circuitry, and a scheme to connect the panel to the driver circuitry. The panel is the unique item. It is manufactured with a combination of semiconductor and thin-film techniques, and with a long list of process steps ranging from glass cleaning through photolithographic definition of electrodes and thin-film depositions of the constituent layers, to final sealing with a cover glass and burn-in.

TFEL is the only major flat display technology in which all of the display is manufactured on a single substrate. In plasma and liquid-crystal displays, the sealing and spacing tolerances of the first substrate to the second and the filling of the gap with gas or liquid are critical for achieving satisfactory display performance. With TFEL displays, the second sheet is merely a protective cover glass. The introduction and broad use of semiconductor manufacturing equipment has transformed TFEL displays to a high-quality manufactured product. It is significant that the five companies who now manufacture TFEL displays or have immediate intentions of doing so (Finlux, Planar Systems, Sharp, Sigmatron Nova, and GTE) use a variety of deposition techniques—including thermal evaporation, rf sputtering, and atomic layer epitaxy, a form of chemical vapor deposition—and use batch or in-line processing. Yet each makes a quality product.

Brighter and darker

TFEL displays are the most aesthetically pleasing of the flat-panel technologies because they are light emitters, produce a pleasing amber color, have crisply defined pixels of uniform luminance, and offer high contrast. The TFEL display appears most like a high-intensity CRT, without the unwanted phosphor reflectance and glare CRTs normally exhibit.

Despite these appearance advantages, TFEL displays do not yet do everything. They are not yet suitable for large (> 6 in.) high-resolution (> 500 rows) displays requiring very high luminance and contrast for viewing in sunlight, or for full-



Source: Sigmatron Nova

Fig. 2: The sharp "knee" in the luminance-vs.-voltage characteristic of a TFEL display allows a high order of multiplexibility without resorting to active matrices and provides a high contrast ratio. The slope of the characteristic below the knee enables the TFEL to exhibit gray scale for direct video display.

color displays. But even in these areas there have been significant advances.

Reducing the dielectric thickness and increasing the phosphor thickness has produced higher luminance by placing more voltage across the phosphor and creating more light-generating centers within it. It unfortunately also places more stress on the dielectric layer. A variation on this theme developed at Sigmatron Nova uses a stacked dielectric layer containing Ta_2O_5 (rather than the conventional SiON) and improved phosphor deposition techniques. The higher dielectric constant of Ta_2O_5 produces a higher voltage across the phosphor without thinning the dielectric layer and reducing its breakdown resistance.

The standard technique for improving the already high contrast of TFEL displays is to use a circular polarizer. Even better is a black light-absorbing layer deposited behind the second dielectric. This creates a dark display screen that absorbs almost all of the ambient light, resulting in sunlight legibility with a display luminance of no greater than 50 fL. This dark-layer approach has been demonstrated in years past, but has not proved practical in production units. Sigmatron Nova now believes that they have a production-worthy dark-field display. It uses a black layer that is chemically and mechanically compatible with the dielectric materials employed and has been demonstrated in laboratory samples to be quite rugged. Plans are under way to incorporate it into the production process.

Living color

Researchers at Tottori University in Tottori, Japan, Ehime University in Ehime, Japan, and elsewhere have developed higher luminance red, blue, and green electroluminescent phosphors that are now bright enough for developmental multicolor panels. Green phosphors, in particular, are now as bright as the conventional amber ones.

Planar Systems of Beaverton, Oregon, has been a leader in developing multicolor displays. With support from the U.S. Army's Laboratory Command (LABCOM) at Fort Monmouth, New Jersey, Planar developed a two-layer, red-green panel that produces a red-green-amber display with no loss in resolution, since the red and green layers are superimposed. Planar recently completed the first developmental RGB panel for producing a

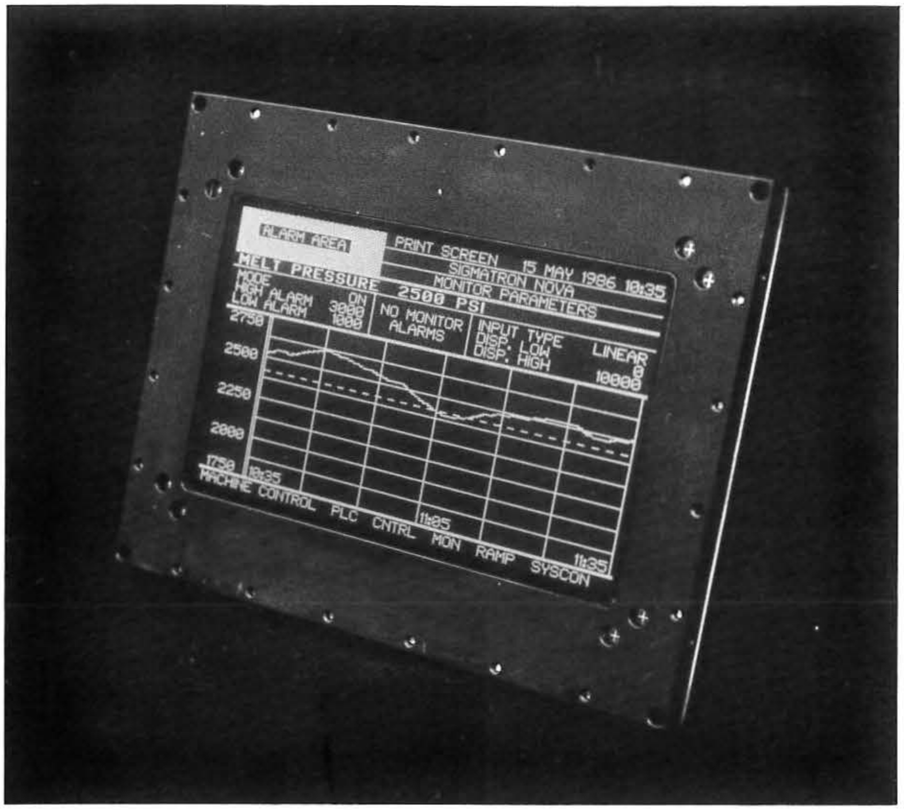


Photo: Sigmatron Nova

Fig. 3: The power consumption of a symmetrically driven TFEL display is proportional to the number of pixels that are lit. In the graphics mode, where there are many unlit pixels, power consumption is comparable to that in a backlit liquid-crystal display.

full multicolor display. The fully operational 6-in.-diagonal display has phosphor triads very much like those in in-line shadow-mask CRTs [see cover photo].

Planar does not predict commercial availability until the early 1990s, but the current prototype convincingly establishes the color potential of TFEL technology.

Applications

Flat-panel applications have been debated hotly and heavily in recent years. The compromise position is that each technology will find its market, with TFEL filling the military and high-end commercial marketplace, and with the various liquid-crystal types being used in more typical commercial and consumer applications. The exact future position of plasma displays is more uncertain.

Both the debate and the attendant jockeying for position have been interesting. With the use of active-matrix addressing to make liquid-crystal displays highly legible has come the push to market them for military applications because production costs have been much higher than anticipated.

The plasma panel, on the other hand, has been appearing in small computers with better user acceptance than that accorded liquid crystals. This is strong evidence of the market's desire for a light-emitting display.

TFEL displays have found application in nearly all market segments, though their sales are quite small at this time. TFEL displays have found their way into an MS-DOS laptop computer, specialized computers and terminals, medical equipment, test instrumentation, process control instrumentation, and a host of military hardware. Plans are afoot for TFEL panels to be introduced into more military equipment, which will use them for computer graphics, live television, and sunlight-legible avionic displays. This mix of applications has come about in part because of the strong CRT-like appearance of a TFEL display. It is therefore rational to contemplate that just as the CRT has become the universal display, so may the TFEL panel. ■

Plasma displays

BY SHIGEO MIKOSHIBA

THE PRICE OF LAND in downtown Tokyo has skyrocketed to $10,000 per square foot, which is the area occupied by a CRT display. Nonetheless, space-hogging CRTs are dominating the world, demonstrating that picture quality, not space, is the most important consideration in display purchases. And CRTs do provide picture quality. They have excellent color purity, gray scale, contrast, viewing angle, response time, and resolution. Above all, they are inexpensive.

CRT dominance is nowhere more evident than in Tokyo's Akihabara district. In the 500 shops selling all manner of electrical and electronic goods, including many personal computers, flat displays are few and far between. Most of those that can be seen are liquid-crystal displays (LCDs), and these are entirely restricted to portable and transportable computer systems.

The CRT's dominance might continue for a few more years, but not forever. I look forward to a bright future for a one-half to one page plasma display, in color. According to Mr. Uchida, who is in charge of fabricating the world's best-selling plasma displays, Matsushita Electronics Corp. is producing 30,000 plasma displays monthly. And Matsushita plans to supply even more, including an 800 × 1024 pixel model with high contrast, low power consumption, and low cost. And multicolor displays are on the horizon.

Shigeo Mikoshiba is a senior researcher at Hitachi, Ltd.'s Central Research Laboratory in Tokyo, Japan, where he works on gas discharge display devices. Dr. Mikoshiba earned a Ph.D. in electrical engineering from the University of Alberta, Canada, after receiving undergraduate and Master's degrees from the Tokyo Institute of Technology. He worked on lasers, fusion, and electrical breakdown phenomena in Canada for several years before returning to Japan to join Hitachi. Dr. Mikoshiba frequently offers a popular seminar on plasma displays at the annual Symposium of the Society for Information Display.

Plasma operation

A plasma display is a collection of miniature gas-discharge lamps working on the same principle as everyday fluorescent lamps and "neon" signs. In these lamps, an electrical discharge is initiated when the voltage applied across the lamp's electrodes rises above a threshold value called the breakdown voltage, V_0. The discharge emits the light.

When the "lamps"—which are the pixels—are arranged in a matrix, images can be displayed by controlling the size and/or duration of the discharge current at each "lamp." This control is accomplished by applying scan pulses ($-V_1$) sequentially to each horizontal electrode and signal pulses ($+V_2$) to the vertical electrodes. V_1 and V_2 are both smaller than V_0 but the sum of them is larger than V_0, so a pixel is turned on wherever the scan and signal pulses occur simulta-

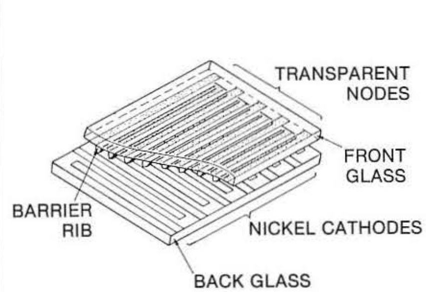


Fig. 1: Dc plasma displays are currently the most popular emissive display for portable computers and are used by Toshiba and Compaq. In dc displays, the electrodes directly contact the discharge glass, which is contained between the front and back glass plates. Barrier ribs separate the plates and prevent discharges from traveling up the cathodes.

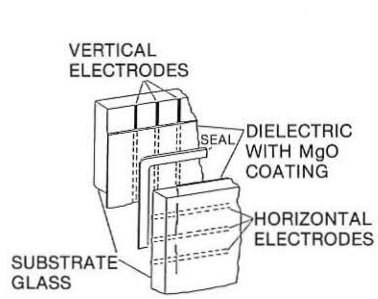


Fig. 2: In ac displays, the electrodes are covered with dielectric layers coated with magnesium oxide. The resulting capacitor creates a memory effect in the display. The magnesium oxide inhibits the sputtering effects that previously shortened display lifetimes. [Illustration from H. G. Slottow, IEEE Transactions on Electron Devices, *Vol. ED-23 (1976), p. 764.]*

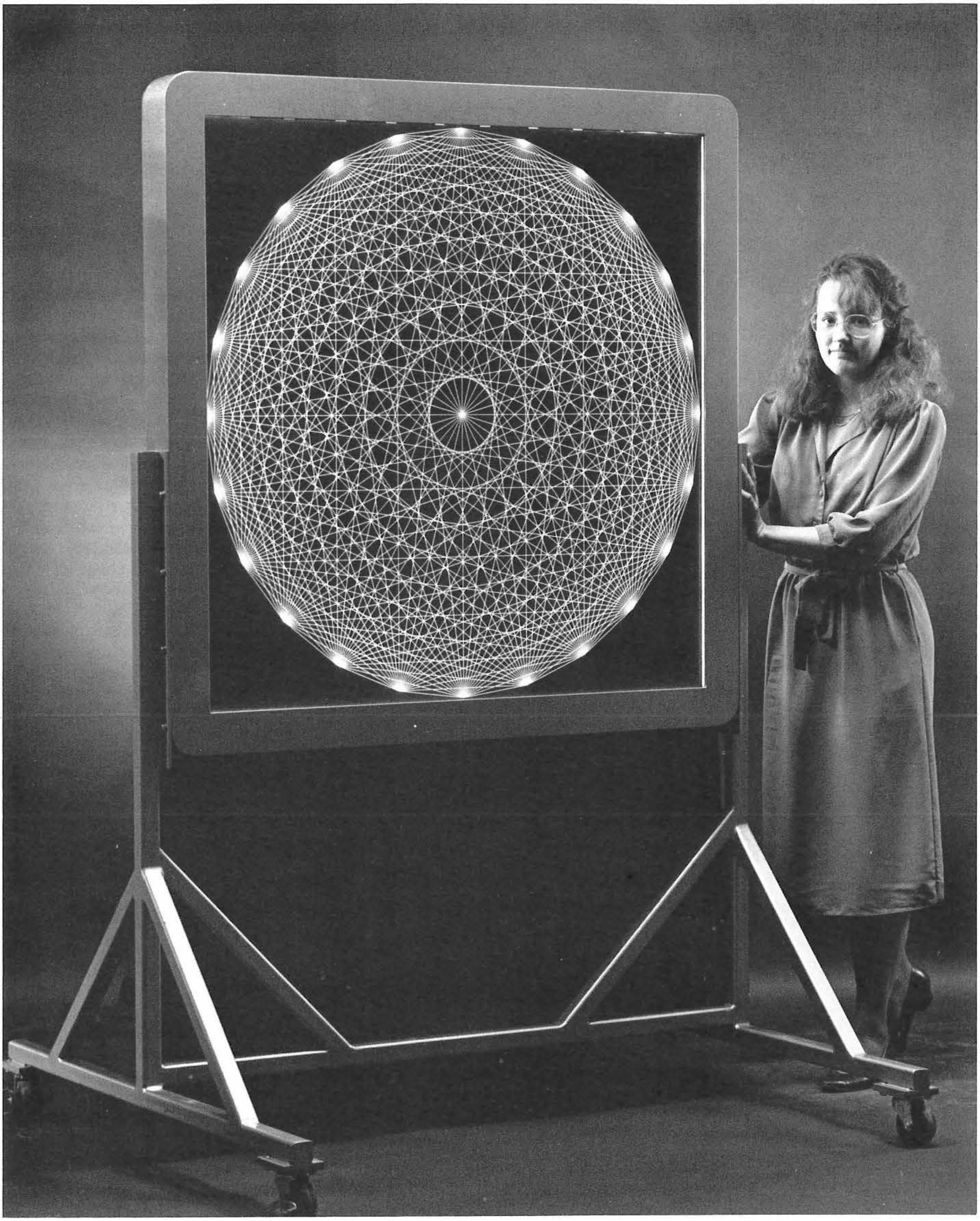


Photo: Photonics Technology

Fig. 3: Plasma displays can be very large. This ac display, part of a complete terminal that uses a Motorola 68020 as the display controller, measures 1.5 m on the diagonal and contains 2048 × 2048 pixels.

Photo: Hitachi Central Research Laboratory

Fig. 4: Though not yet ready to hang on the wall, experimental full-color plasma television displays have been fabricated. This one has a 20-in. diagonal and a 0.65-mm average discharge pitch.

neously. Once a pixel's electrical discharge is turned on, it will stay on even if the voltage across the pixel drops below V_0.

A pixel's color can be determined by the discharge gas itself, or by phosphors inside the discharge spaces. The familiar orange-red display uses the light emitted by the neon in the gas that fills the discharge volumes. If phosphors are used, they can be excited by the vacuum ultraviolet (VUV) light emitted by the gas in the panel, as in conventional fluorescent lamps.

The electrical discharges interact vigorously with the surrounding materials. Thin layers of these materials (including metals) can be removed from one part of the discharge container and deposited elsewhere. This process, known as sputtering, is responsible for the dark films that form at the ends of fluorescent lamps as they age. It can change the plasma panel's discharge characteristics and shorten its useful life.

But sputtering is now well controlled. That many of the plasma-based Nixie™ tubes commercialized in the 1950s are still going strong indicates the basic reliability of the plasma technique. Panel life is today typically 20,000 hours, with some panels going to 100,000 hours or more. Use of the chemically stable rare gases that extend panel life also eases environmental temperature constraints. The typical temperature range is $-5°C$ to $+55°C$, which is far less restrictive than typical ranges for LCD panels.

Ac or dc?

Plasma displays are categorized mainly by whether the signals applied to their discharge electrodes are dc or ac, although there are also hybrid types such as dc-ac and dc-CRT.

A typical dc display [Fig. 1] consists of a front glass plate with anodes (positive electrodes) and a back glass plate with cathodes (negative electrodes) that are perpendicular to the anodes. Barrier ribs provide spacing between front and back plates and prevent the discharge sites from spreading along the cathode surface. Thick-film printing of the screen patterns is the least costly fabrication technique. It is also the most frequently used, except in depositing the transparent anodes, which require thin-film techniques.

The discharge gas used most frequently is neon mixed with 0.5% argon. The small amount of argon reduces the breakdown voltage of the discharge gas by about 20%—a useful characteristic well known as the "Penning effect."

The electrodes of dc panels are exposed to the discharge gas; those on ac panels are insulated by thin-film dielectric layers with a magnesium oxide (MgO) coating on the surface [Fig. 2]. The MgO's low sputtering rate promotes long life.

Ac plasma panels have inherent memory. Once a discharge is ignited by the application of a "write pulse," it stays on as long as "sustain pulses" are applied. The result is a brighter, flicker-free display that has no need for an external memory.

Memory for dc panels can be achieved by applying either a dc sustain voltage that is slightly smaller than the breakdown voltage or by applying a sequence of pulses to the discharge electrodes.

Plasma display characteristics

The simplicity of the plasma panel's structure makes possible a rugged and large-area display. A 1.5-m-diagonal, 2048 × 2048 pixel, 2-line/mm display was announced by Photonics Technology of Northwood, Ohio, and Magnavox Government and Industrial Electronics Co. of Fort Wayne, Indiana, in early 1987 [Fig. 3]. Donald K. Wedding, Sr., president of Photonics Technology, believes that diagonals of up to 3 m are possible with ac plasma. Photonics has produced and delivered to a military customer displays with a resolution of 5 lines/mm in a 1024 × 1024 pixel display. If operated in a memory mode, plasma panels can provide dot luminance of 1000 fL or more.

Because plasma displays rely on the movement of electrons in a gas, they exhibit fast response times. This allows the panel to express gray scale using a pulse width/pulse number modulation technique. For computer-terminal applications, 8–16 gray levels can be expressed to obtain compatibility with color CRTs.

Sharp knees and gas logic

Because of the strong current-voltage nonlinearity that produces a sharp "knee" in the current-voltage curve, contrast ratios of 100:1 or more can be achieved. This nonlinearity also permits the addressing of many electrodes with a time multiplexing technique. Therefore, the complicated active-matrix addressing needed for LCD TV is not required for plasmas.

If we think of the voltages V_1 and V_2 as inputs and light emission as an output, the gas plasma discharge element can be regarded as an AND gate. If you prefer your AND gates to be completely electronic, a third electrode in contact with the discharge can furnish an output signal that indicates the presence or absence of a discharge. By using these signals, the number of scan pulse drivers can be reduced by a factor of 10 or more—a technique known as "gas logic."

More AND logic for a given pixel can be had by using "priming," in which the breakdown voltage is reduced by introducing charged particles, metastable atoms, or photons into the discharge vessel. If one of several discharge sites is primed, it is the one that will be selected for ignition.

Priming is readily incorporated into a plasma display panel by furnishing each display pixel with two discharge vessels, one for priming and the other for display. Although the total number of electrodes increases, the AND logic of the priming and signal voltages permits the number of total external circuit drivers to be reduced even further.

Another benefit of priming discharges is a reduction in the time it takes a discharge to ignite from roughly 100 to 10 μsec following the application of suitable voltages to the electrodes. As a bonus, this also reduces the time jitter in initiating the discharge. The overall result is a more stable and uniform brightness across the display area and a faster scan rate. This technique is utilized in most plasma displays. In the display illustrated in Fig. 1, priming is accomplished by auxiliary discharges that scan the entire panel along the length of the anodes, regardless of the data signals.

Plasmas and batteries: the odd couple

Commercial plasma displays have luminances in the range of 10–100 fL. These values are acceptable for data and graphic displays used under controllable ambient illumination. But the luminous efficiency of these displays is typically 0.2 lum/W, which corresponds to an energy conversion efficiency of only

0.08% for white. This value is too low for a battery-powered display.

Plasma's low efficiency originates in the inefficient process of maintaining the electric current in the discharge. The usual mechanism relies on the release of electrons from the cathode by high-energy ion bombardment. Because the electron emission coefficient typically lies between 0.01 and 0.1, most of the electric power goes to heat the cathode.

Plasmas discharge in colors, too

To provide colors, VUV radiation at 147 nm from the xenon glow is used along with various phosphors. Full color is accomplished by incorporating red, green, or blue phosphors into neighboring discharge sites, and controlling the intensities of each color using the gray-scale technique. Color purities of ultraviolet excitation phosphors are comparable to those for color CRTs.

Although most plasma display panel manufacturers are investigating color displays extensively, only a few displays exist today that emit colors other than neon-red. Other colors are being kept off the market by the short lifetimes of the phosphors, which are degraded by sputtered materials from the cathode, by the VUV irradiation, and by ion bombardment.

Ikura desu ka? (How much does it cost?)

Even with equal quality and color capability, plasma displays will be able to compete directly with CRTs only when their cost has been reduced. As Dr. Larry Weber of the University of Illinois points out, the high cost is due in part to insufficient volume production, but is due more seriously to the large number of circuit drivers required by any matrix display.[1] The increased use of internal gas logic has the potential to solve this problem. Those implementations of gas logic that greatly reduce the electronics costs without significantly increasing panel complexity will receive wide market acceptance.

Flat-panel television

A number of experimental full-color plasma displays have been fabricated for application to flat-panel TV with sizes in the 20-in.-diagonal range [Fig. 4]. In the future, 40-in.-diagonal panels will be fabricated that maintain today's resolution. These will be designed for high-definition television systems having 1000 scanning lines and 60 fields/sec. White peak area luminance is 17 fL, with 256 gray levels.

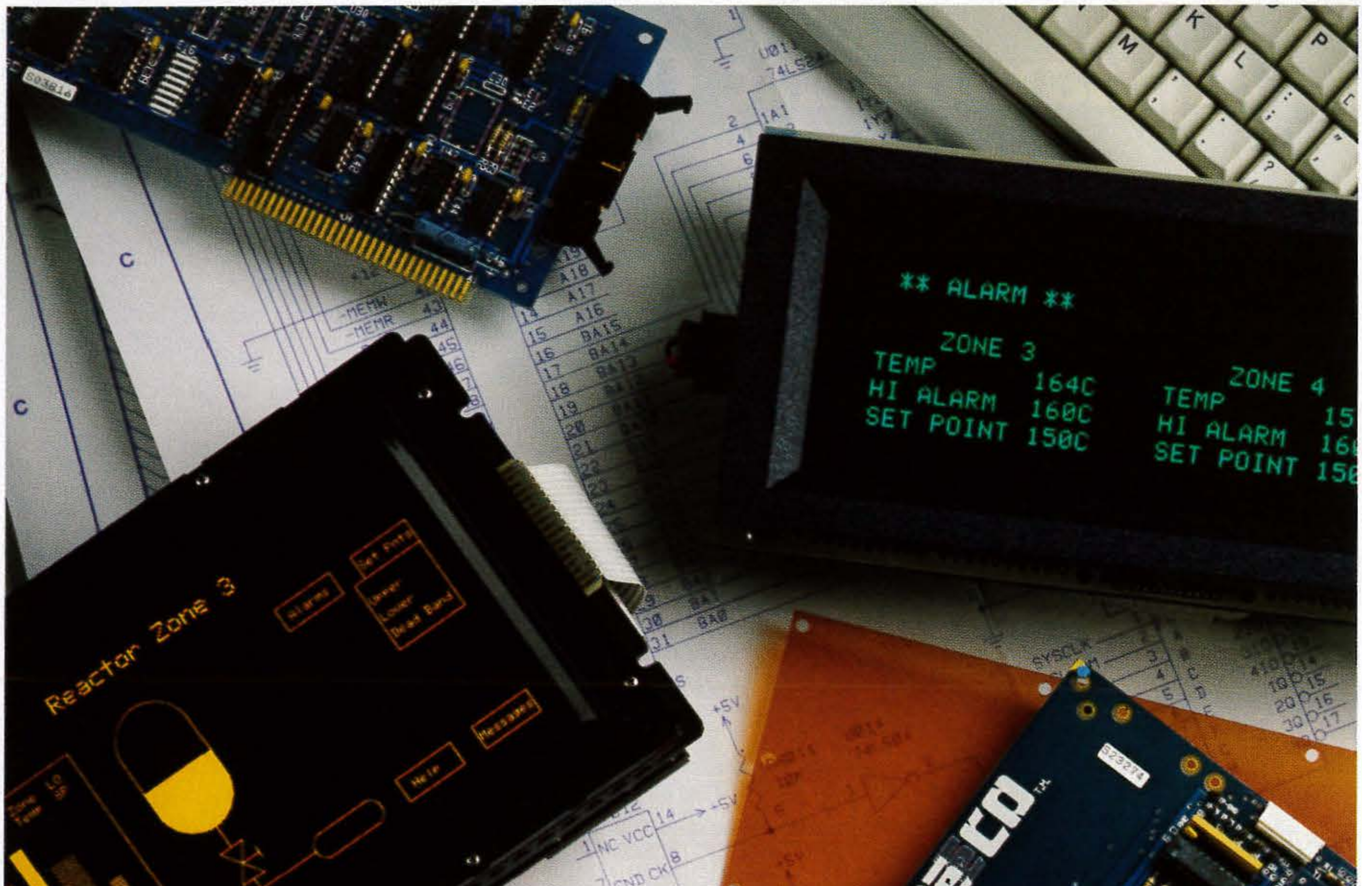
Another approach to flat TVs is to utilize a hybrid dc-CRT technique, in which discharge electrons are accelerated to excite a phosphor, rather like existing CRTs in which accelerated beam electrons bombard the phosphor. Both 35-in. monochrome and 8.5-in. color displays of this type have been fabricated.

For color TV displays, luminance and efficiency an order of magnitude higher than those found on today's plasma displays will be necessary.

Notes

[1]L. F. Weber, "Plasma Displays for Portable Computers," *Information Display*, Vol. 4, No. 4 (April 1988). ■

Circle no. 12



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Large masks for flat panels

BY RIC CORLESS

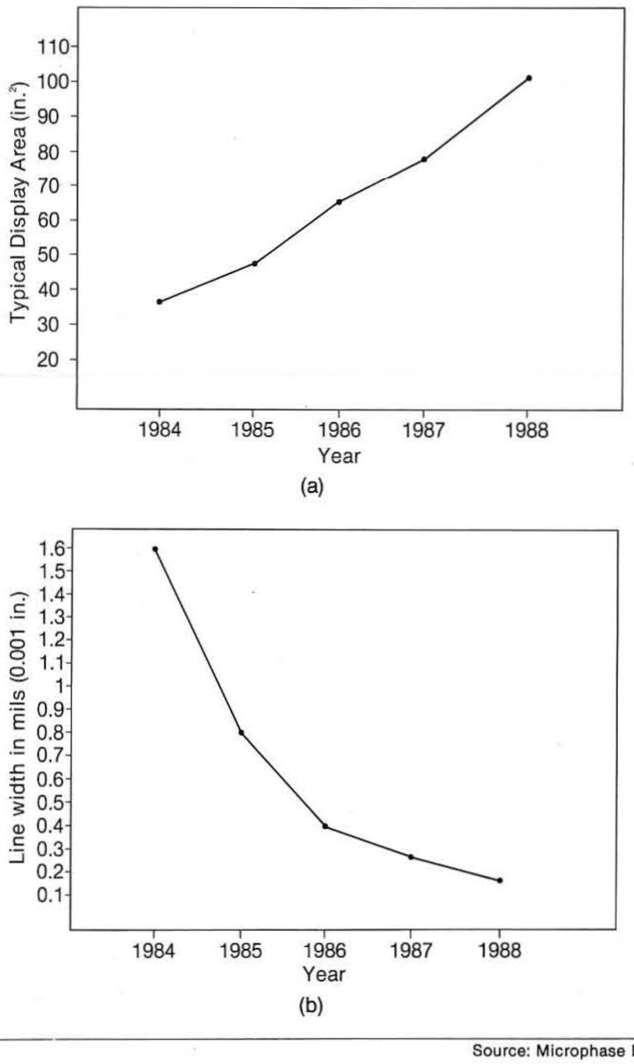
As THE STATE of the flat-panel-display art has shifted from small, statically driven, segmented displays to large, multiplexed dot-matrix formats, the lack of more precise large masks for establishing electrode and active-element patterns on flat-panel displays has become a significant problem for U.S. display manufacturers. The applications are there. The markets are there. But the necessary masks have not been available [Fig. 1]. For the most part, mask shops have offered a choice: high precision or large area . . . but not both.

Applying IC technology

The most widely used techniques for manufacturing masks for flat-panel displays emerged from printed-circuit-board technology. While useful for many applications, those techniques have limitations—particularly when it comes to building bigger and sharper displays.

These limitations are inherent in the technology. The materials used—usually silver-halide photographic emulsion on a flexible mylar or polyester film—are sensitive to temperature, humidity, and handling damage. Layer-to-layer registration tolerances for the complex masks required for flat panels are rarely better than ±1.0 mil, and dimensions within a layer are typically 2.0 mil.

Ric Corless is vice president of engineering at Microphase Laboratories, Albuquerque, New Mexico. He manufactured integrated-circuit masks for 20 years before founding Microphase with Martin Boothman in 1984.



Source: Microphase Laboratories, 1988

***Fig. 1:** The active area of flat-panel displays has been growing steadily over the past five years (a), and the sizes of the smallest features in these displays has been shrinking (b). This combination of larger size and greater precision has pushed the capabilities of the field's traditional mask-making technology to its limits and beyond.*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These tolerances were too loose by an order of magnitude for devices such as one that Xerox Corp. was developing in 1985, and the required precision of $\pm 50 \times 10^{-6}$ in. had to be held over a 12-in. array. Xerox joined forces with Microphase Laboratories, a small start-up company, to develop ways of making the needed masks based on the techniques used in the integrated-circuit industry for making their very-high-precision masks.

These masks include a substrate made of glass instead of film, and an 800-Å layer of chromium as the masking medium instead of a photographic emulsion [Fig. 2]. The first step in making the masks is depositing the chromium onto the glass substrate. Photoresist is applied and then exposed to intense ultraviolet light by sophisticated imaging equipment controlled by a CAD-produced data tape. Chemical processes dissolve the photoresist that has been exposed to light but leave undisturbed the areas that have not been exposed. An acid bath etches away the chromium exposed by the resist that had previously been dissolved away. After rinsing, the remaining photoresist is stripped off, leaving a mask of chromium images on glass.

Controlling production equipment with laser interferometry and maintaining very stable manufacturing conditions permits the routine delivery of masks with guaranteed specifications of $\pm 50 \times 10^{-6}$ in. over dimensions as large as 14 in. The standard specification for layer-to-layer registration is $\pm$ 0.1 mil, which compares favorably to the previous standard of $\pm$ 1.0 mil. Individual images have excellent edge acuity and there are no fuzzy areas between clear and opaque features. Linewidth is held to $\pm$ 0.02 mil [Fig. 2].

Also, because glass is less sensitive to changes in temperature and humidity than film and because chromium is much less susceptible to damage than thick, delicate layers of emulsion, masks manufactured using this technique (which was developed by Microphase for flat-panel displays) are very stable in stressful environments, are easily cleaned, and usually last much longer than film masks.

New products from improved technology

The new masks have enabled Planar Systems, Inc., of Beaverton, Oregon, to bring to production a product they were unable to develop with the old technology. The chrome-on-glass photo tools are precise enough for Planar to take a pair of masks and combine them for a total display size of 13½ × 15 in. On a 1000 × 800 display, tolerances of just a few micrometers permit pairing the masks so the features butt up precisely, according to Steve Veenstra, a technical associate at Planar.

The new masks also allowed Litton Panelvision in Pittsburgh, Pennsylvania, to increase the resolution of an existing display. Panelvision's chief scientist Paul Malmberg: "We made the same size displays before with wider spacing between the picture elements. Then, the distance from center to center was 12.5 mil; now it's 6.25. The other features are much smaller as well, so we now have a much higher resolution liquid-crystal dot-matrix display."

Lasers and steppers

Another approach to producing larger, more precise masks is the laser photoplotter. Working with photographic emulsion on glass, the photoplotter delivers larger masks and better precision than polymer

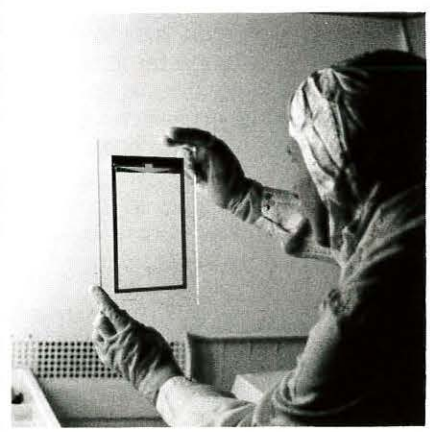

Fig. 2: Large high-precision masks for defining the electrode and active-element patterns in flat-panel displays can be made with a thin layer of chromium on a glass substrate. This technology, adapted from the integrated-circuit industry, is far more precise than the one based on a photographic emulsion and polymer film, which had been adapted earlier from the printed-circuit-board industry.

masks, but it does not yet offer the precision or linewidth control of chrome on glass.

A direct-write step-and-repeat process being developed by three companies—Nikon of Tokyo, Japan, Aset Corp. of Woodland Hills, California, and MRS of Westland, Massachusetts—may offer another option. With precision comparable to chrome-on-glass masks, the new steppers promise to deliver even larger mask sizes. Currently, Nikon expects to manufacture up to 12 × 12 in. formats, Aset up to 14 × 14 in., and MRS up to 17.7 × 17.7 in.

Stepper production is relatively slow, topping out at 30 panels per hour vs. the several hundred per hour flat-panel display manufacturers obtain by using contact printing. The advantage of stepping is that the defect density is low.

To increase throughput, Microphase foresees a mix-and-match strategy: layers with critical defect density could be stepped, while other layers could be contact printed. Obtaining the highest degree of precision possible in the masks is still essential, however, since the stepped masks must align with the contact-printed layers. But step-and-repeat will probably be used only where it is absolutely necessary: steppers sell for \$1–\$1.5 million.

Whatever options flat-panel display manufacturers pursue, viable alternatives to printed-circuit-board technology are now available and they extend production capabilities far beyond those imagined just a few years ago. ■

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