Scanning Electron Microscopy

Volume 3
Number 1 *3rd Pfefferkorn Conference*

Article 24

1984

Displays: Market and Technologies

Steve Blazo
Tektronix Inc.

Electron Optical Systems (pp. 231-236)
SEM Inc., AMF O'Hare (Chicago), IL 60666-0507, U.S.A.

0-931288-34-7/84$1.00+.05

DISPLAYS: MARKET AND TECHNOLOGIES

Steve Blazo

Tektronix Inc.
P.O. Box 500
Beaverton, OR 97077
Phone No. (503) 627-4885

Abstract

Displays provide the essential human interface to virtually all electronics instrumentation. The market is large with new applications appearing every year; sometimes with profound impact. Digital watches with liquid crystal displays appeared in the early 1970s and have virtually wiped out the mechanical timepiece industry. Personal computers with cathode ray tube (CRT) displays are proliferating with diverse applications in the industry and in the home. Work stations with high-resolution color displays are changing the way architects, draftsmen, and IC designers perform their job. The CRT is the dominant technology in today's market, and will, no doubt, continue to be for some years to come. High-resolution shadow-mask tubes will capture a larger and larger market share in the coming years. Projection displays will grow rapidly with the introduction of systems based on new technologies and with the advent of high definition TV. The flat panel industry is growing at 30 percent per year, not so much from taking business away from CRTs, as in the creation of new applications. This is an area rich in technologies with many contenders such as plasma, electroluminescence, liquid crystal, vacuum fluorescent, electrochromic, and others.

Key Words: Display, Cathode Ray Tube, Liquid Crystal, Electroluminescence, Plasma, Projection display.

Introduction

Displays are the primary man-machine interface. Information passed through them is input to man's most powerful sensory organ, his eyes. With the addition of peripheral devices such as a digitizing tablet, touch panel, keyboard, and computer, the collection becomes a powerful system for analyzing and controlling information and machines. Therefore it is not surprising that display technology has been a field of active research and development, and that a large number of related technologies exist or are being developed to satisfy this need.

Virtually every physical phenomenon that could be imagined to produce a reversibile visible image has at some time or another been investigated for use as a display medium. These are listed in figure 1 where no attempt has been made to be exhaustive. Most of these methods, while novel and inventive, have not met with commercial success. Display market segmentation is shown in figure 2. Note that the market today is dominated by the CRT and will no doubt continue to be for some time to come.

CRTs can display large amounts of data at very low cost. This is in large part due to its inexpensive analog addressing. When a particular display element is to be activated, all that need be done is supply the appropriate currents to the deflection yoke and pulse the grid. This can be done at high resolution and very low cost. Monochrome 500-line resolution CRT modules can be purchased for $100 or less, corresponding to 0.04 cents/pixel. This cost is not approachable by any other technique. In addition CRTs have the capability of presenting information in full color, at high brightness, and with rapid update. The main disadvantages of the CRT are its relative bulk, limited size, and the necessity of supplying high voltage. The cost of CRT displays is also relatively insensitive to the amount of data presented; that is, a 50-line resolution module would cost about the same as a 500-line resolution module.

Applications requiring just a few numerals or lines of text are the areas where non CRT based technologies have had their greatest impact. These displays typically have the asset of being flat and not taking up much room. Flat panel displays are typically addressed by an orthogonal matrix of leads with a display element at each intersection. When a particular x and y lead is energized with $\pm$V, the voltage across the intersection will be 2 V; at least twice that across any other intersection in the matrix. If the display medium

Light Emission
- Plasma Discharge
- Cathode Ray Tubes
- Electroluminescence
- Glowing Filament

Material Transport
- Deformed Membranes
- Rotating Balls
- Electrophoretic
- Colloidal Needle
- Oil Film

Optical Activity
- Liquid Crystal
- Ferroelectrics
- Magneto-optic

Electrochemical
- Electrochromics
- Reversible Electroplating
- Reversible Redox

Figure 1. Physical phenomena researched for display applications.

CRTs (all types)	$4,650
LED	$ 550
LCD	$ 486
Gas discharge	$ 110
VFDs	$ 71
Incandescent	$ 17
Other	$ 5
Total	$5,889

Industrial	$ 330
Color TV consumer	$4,080
Black & white TV consumer	$ 240
Total	$4,650

Source: *Stanford Resources*

Figure 2. a) Estimated worldwide market for electronic displays (millions of dollars, 1982). b) Estimated worldwide market for cathode ray tubes (millions of dollars, 1982).

is chosen with a sufficiently nonlinear response, only that element will be activated. Examples that work well with this technique are plasma and electroluminescence. This simple matrix addressing technique is by far the lowest cost but requires very special properties of the display media.[6] The alternative is to place active nonlinear circuit elements in series with each display pixel by, for example, fabricating the display on a wafer of silicon patterned with the appropriate circuits. An example of this technique is the miniature liquid crystal pocket TVs under active development in Japan.[27]

Light emitting diodes (LEDs) have emerged in the last decade as the most successful technology for numeric indicators. Their strength lies in their reliability, low cost, high brightness and compatibility with low voltage integrated circuits. Major disadvantages of LED displays are their high power consumption and difficulty in fabricating for high information content. Liquid crystal (LC) displays, the next largest market segment, are growing at a rapid rate. A major asset of liquid crystal displays is their extremely low power consumption. In addition, being passive, they have good visibility in high ambient light conditions. The market for non-watch LC displays is growing at 30 percent per year. Matrix-addressed LC displays are available capable of presenting 4 lines of 40 characters per line. I expect matrix-addressed LC displays to dominate the flat panel market by 1990. Plasma or plasma gas-discharge displays have been highly developed over the last few years. For large alphanumeric applications plasma displays represent the main challenge to CRTs. Vacuum fluorescent displays are used extensively as indicators in TVs, stereos, and electronic instrumentation. In recent years high-information-content vacuum-fluorescent displays have become available, although their size will always be limited by vacuum considerations.

CRT Displays

The conventional CRT is a well known device, widely used in a variety of systems ranging from oscilloscopes to the home television receiver. All CRTs consist of: a cathode, or source of electrons; a beam forming structure, consisting of various electrodes; a deflection apparatus to steer the beam; and a screen, consisting of a thin phosphor that is luminescent under electron bombardment. CRTs come in many forms but they are most easily characterized by whether they use electrostatic or magnetic deflection.

Electrostatic deflection is used where very high speeds are required in the deflection, such as in oscilloscope tubes. Scan expansion techniques are used to get the high deflection sensitivity required by high-speed amplifiers. In the past, high deflection sensitivity has been achieved with a domed mesh separating the electron gun from a high voltage (20 kV) accelerating field applied to the tube envelope and phosphor screen (see figure 3). This configuration results in a diverging lens which expands the scan and also results in high brightness due to the high energy imparted to the electron beam. The mesh causes some undesirable results such as reduced beam current due to interception on the mesh wires, halo due to scattered electrons off the mesh, and a reject rate due to contamination.

Recently Tektronix has introduced a new CRT product line based on a meshless scan expansion technique.[12] Meshless scan expansion is accomplished with a lens between the deflection plates and the screen which applies an accelerating field with a large quadrupole component to the beam. The scan in one axis is diverged and in the other axis is strongly converged so that the beam trajectories cross the axis and then expand again.[5] This configuration achieves a net scan expansion in both axes without the undesirable features of a mesh. This relatively new design also achieves a higher deflection sensitivity, higher brightness, and a smaller trace width than the domed mesh design.

To achieve very high beam brightness, other electrostatic tubes use a microchannel plate multiplier that is placed in close proximity to the screen.[11] The microchannel plate consists of a large number of small (25 micron) diameter channels etched in a thin sheet of glass. The walls of the channel are made slightly conductive. When a voltage is applied across the plate input electrons cascade down the channel and are multiplied by secondary emission. Gains of 10^4 are easily achieved.[16] Microchannel plate multipliers are typically used to display very high speed transients or low duty factor events. A major factor limiting their more widespread use is the high cost of the multiplier plate.

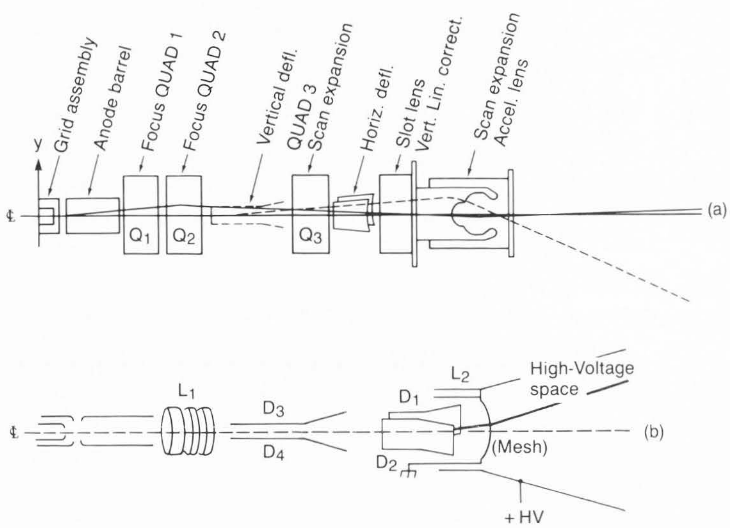

Figure 3. Electrostatic deflection CRTs commonly used in oscilloscopes; a) Tektronix meshless scan expansion CRT b) Mesh-lens post deflection acceleration CRT.

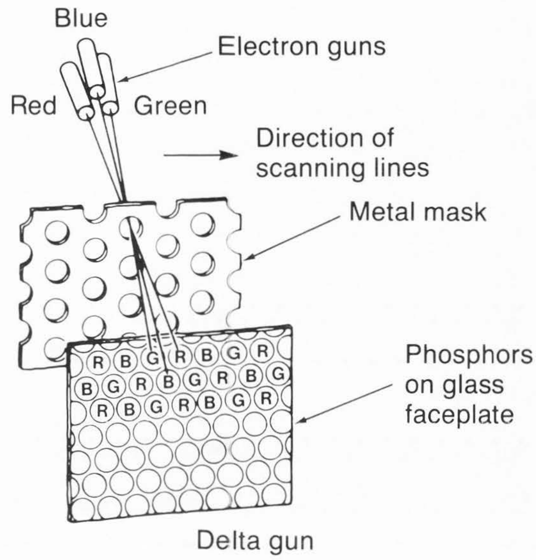

Figure 4. Principle of color selection of the delta gun shadow mask color tube.

Magnetically deflected CRTs form the greater bulk of the entire display market. These CRTs can be characterized by whether they are stroke written or raster scanned and whether they are monochrome or color. The trend in recent years is toward high resolution raster-scan color shadow-mask CRTs.

One type of stroke-written CRT is the bistable storage tube introduced by Tektronix in the early 1970s in a line of graphic computer terminals. With this tube an image is stored on the phosphor using its secondary emission properties and viewed by flooding the screen with a low voltage (200 V) spray of electrons.[14] The bistable storage technology offers resolution up to 4000 × 4000 pixels and gives superior graphics capability at low cost. Disadvantages are low brightness, lack of grey scale, slow update, and monochrome only display. For these reasons direct view storage tubes (DVST), as they are called, are rapidly losing market share. Conventional stroke-written CRTs can be either color or monochrome. Color can be achieved by beam penetration or by use of a shadow mask. The phosphor of a beam penetration tube consists of two layers, each layer luminescent with a different color. With a low energy electron beam (8 kV) only the outer layer of phosphor is excited. When the beam energy is higher (15 kV) both layers are excited and the display has a different color. Stroke-written CRT display systems are typically used to present stick-figure images in computer-aided design work stations, a task they do very efficiently with a minimum of computer power. This conservation of computer power is especially important where dynamic images are to be presented. With the advent of increased computer power this advantage is of less importance and stroke-written systems are losing market share to raster-scanned systems.

High-resolution raster-scanned color shadow-mask tubes are the most rapidly growing display market segment. The principle of color selection is shown in figure 4.[7] The red, green, and blue beams, typically arranged in a delta configuration, come through the shadow mask holes at slightly differing angles and therefore can only illuminate their respective phosphor dots. Each screen is individually fabricated for a particular mask/panel combination with an optical exposure that uses the shadow mask itself as the exposure mask. The process requires tight process control but lends itself well to mass production. In recent years the Japanese have become the dominant supplier by a significant margin. Since three beams are used some means must be provided for convergence so that all three rasters fall on top of one another. This is typically done by dynamic convergence coils on the neck of the CRT and a rather complicated calibration procedure. In recent years the trend in color tube design has been toward higher resolution and to the use of in-line self-converging guns and yokes.[19] Screens with resolution of 0.012 in (0.3 mm) between triads are available from a number of suppliers in sizes up to 19 inch (482.6 millimeter) diagonal. Screens with a resolution of 0.008 in (0.2 mm) are beginning to become available. This dimension is near the resolution limit of the eye at normal viewing distances. The basic advantage of the in-line tubes is self convergence. The combination of in-line guns and a yoke especially designed to give higher-order harmonics in the deflection field allows convergence of the three beams over the entire screen. The need for dynamic convergence circuits and magnetic drivers on the CRT neck, as used on the delta gun tubes, has been eliminated at a substantial cost reduction and ease-of-use improvement. A disadvantage of self-converged, shadow-mask tubes is a somewhat larger spot size compared to non-self-converged tubes. Recently an autoconvergence technique has been introduced based on a photomultiplier pickup of a pattern deposited on the gun side of the shadow mask.[3] This technique eliminates user-controlled convergence adjustments and may breathe new life into the delta gun approach.

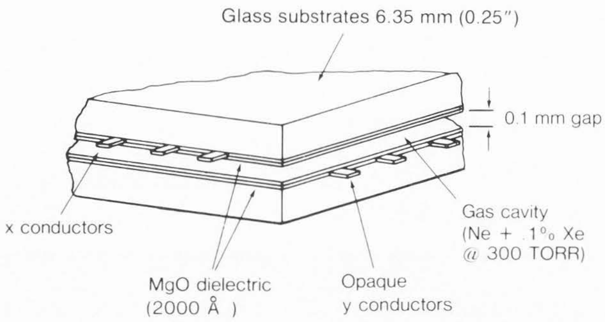

Figure 5. AC plasma panel construction.

Plasma Displays

Gas-discharge displays utilize the light output of a cold-cathode discharge.[22] The process is relatively efficient; especially in neon for which the characteristic orange emission has an output efficiency of .05 Lumens per Watt. A major advantage of gas discharge for display devices is the existence of a sharp threshold. This allows a large number of lines of information to be matrix addressed without crosstalk. An example of a plasma display cell is shown schematically in figure 5. The typical plasma display panel consists of a matrix of gas discharge cells defined by two sets of orthogonal electrodes. These are deposited on two glass substrates which are spaced and filled with a neon-argon gas mixture. Spacing of 0.004 in (0.1 mm) and pressures of 100 torr are typical values. Plasma panels may be operated in two basic modes, AC and DC.

In the AC mode the electrodes on the device are covered with an insulator film.[21] A charge deposited on the insulator during the gas discharge aids the polarity-reversed applied voltage on alternate half-cycles to break down the gas again. Thus, once initiated by a writing pulse, the gas discharge can be maintained with a lower value of applied sustaining voltage and the panel exhibits memory. The use of the insulator eliminates the need for current limiting resistors that would be required for bare electrodes. AC plasma panels typically do not exhibit grey scale since they are essentially bistable memory devices. This memory eliminates the need for display refresh and the associated flicker. In addition, the brightness is independent of display area. The maximum size of AC plasma displays is therefore limited only by manufacturing constraints such as the ability to manufacture large fine electrode grids at high yields. AC plasma technology is the basis for the largest non-projection displays in the industry. Photonics Technology offers a display panel measuring one meter diagonally and has plans for even larger panels in the future. The IBM 3290 terminal, recently announced, uses an AC plasma display. This display has a viewing area of 340 × 274 mm (13.4 × 10.8 in) and a resolution of 960 × 768 lines. This viewing area gives the terminal the ability to display 69 lines at 160 characters/line. Numerous halftone patterns are available to give the appearance of grey scale. The display subassembly itself costs $4,500 including associated electronics.[2]

DC plasma panels were widely used in the past under the trade names "Nixie" and "Self-Scan" manufactured by Burroughs Corp.[17] Burroughs has recently dropped this product line and is concentrating on a modification of the AC panel for future products. DC plasma panels typically do not exhibit memory and must be constantly refreshed. Display brightness is inversely proportional to the number of lines addressed since each line is only on that fraction of the time. There are several companies looking at DC plasma devices especially for TV application. This is because grey scale is relatively easy to achieve through current or duty cycle modulation. Sony Corp. is very active in DC plasma and has reported on a high-resolution panel that includes a trigger electrode in addition to the usual x y matrix. This trigger electrode greatly reduces the voltage and thus the cost of the drive electronics.[1]

Major disadvantages of plasma panels are fabrication and electronics costs and the difficulty in achieving full color output. Nevertheless plasma panel applications will continue to grow where the form factor is of chief importance such as for highly portable instrumentation and military applications.

Liquid Crystals

Many organic molecules, due to their polar nature and elongated shape, exhibit long range orientational structure in their liquid state. This intermediate state between solid and liquid is known as the mesomorphic-or-liquid-crystal state. This state occurs in a relatively narrow temperature range, the material being either solid or liquid outside this range. Liquid crystals exhibit an anisotropic index of refraction and dielectric constant typically described by two constants, one along the long axis and one perpendicular to it. As a result the material exhibits a birefringence effect that can be controlled by external electric fields or heat. This effect is of prime importance in display applications.

Liquid crystals may be classified into three basic types: nematic, smectic, and cholesteric. In nematic liquid crystals the rod-like molecules line up parallel to one another. Smectic liquid crystals exhibit a layered structure with little order within a layer. Cholesteric liquid crystals are similar to nematic with a gradual helical twist normal to the director.

The most commonly used liquid crystal displays use the twisted nematic field effect.[15] The display consists of two glass plates with rows and columns of transparent conductors. Sandwiched between the glass plates is the liquid crystal mixture 10 to 50 microns thick. The alignment of the molecules is arranged parallel to the glass plates by evaporating a thin layer of SiO onto the glass at an oblique angle or by rubbing the surface. On assembly the plates are mounted with the alignment perpendicular to one another. As a result the molecules exhibit a 90 degree twist across the cell (see figure 6). This structure has the effect of giving light, plane polarized in the direction of one rubbing axis, a 90 degree twist as it passes through the cell. When a voltage is applied to the cell the molecules line up perpendicular to the glass surfaces, and plane polarized light passes through unaffected. The addition of polarizers on both sides of a display gives either a white-on-black or a black-on-white display. Since the effect is entirely due to the field, the total power can be a few microwatts per square centimeter. The twist cell has a slow response (50 ms) and a soft threshold which limits the number of lines that can be addressed in a simple matrix fashion. Nevertheless, panels are available with a resolution of 4 lines of 40 characters at low cost; and this is improving month by month.[20]

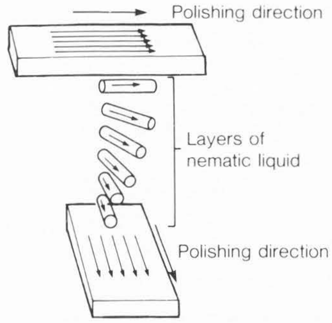

Figure 6. Alignment of molecules in twisted nematic liquid-crystal cell.

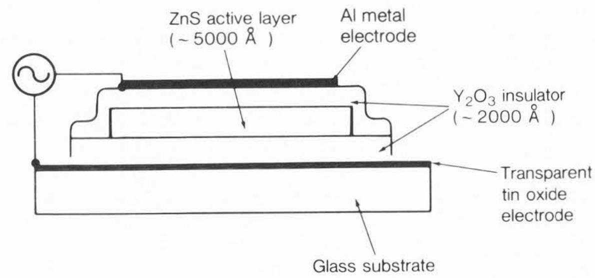

Figure 7. Structure of thin film EL device.

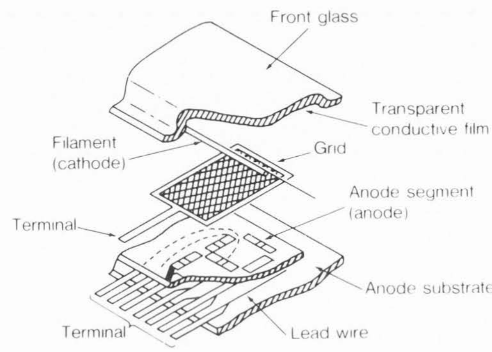

Figure 8. Vacuum fluorescent display.

The dye liquid crystal cell is another approach. In this case a plechroic dye, which has molecules exhibiting anisotropic absorption, is dissolved in the liquid crystal host. Light is attenuated by differing amounts depending on the orientation of the liquid crystal molecules and no polarizer need be used.[25]

One solution to the matrix addressing problem is the active substrate liquid crystal displays. This approach uses an array of transistors, often fabricated on a large single-crystal silicon wafer. One transistor is provided for each pixel allowing faster switching, better grey scale, and a much higher information content. Difficulties in making large defect-free transistor arrays has so far limited the commercialization of this technique, but it is an area of very active research, especially in Japan.[13,18]

Thermally-addressed smectic liquid crystal displays require the presence of both heat and electric field for activation. For these a smectic liquid crystal is used that freezes either clear or cloudy depending on whether or not a voltage is applied during cooling. This effect yields a storage display. The image is normally viewed in projection and is capable of very high resolution. Recently IBM has reported on a 64 million pixel display which uses an array of scanned solid-state lasers to supply the heat.[4]

The advantages of liquid crystal displays, namely low power, low voltage, passivity, and low cost, outweigh the disadvantages. So the use of liquid crystal displays is rapidly increasing.

AC Electroluminescence

AC electroluminescence (ACEL) is a phenomenon where light is more or less uniformly produced in the bulk of a material under the application of a strong electric field. It has been investigated by numerous researchers in various configurations.[9] The most popular structure of the device is shown in figure 7. The light generating mechanism is believed to be due to impact excitation of the manganese ion. The presence of the dielectric layers prevents current runaway and promotes a more uniform current distribution. The advantages of the structure were first demonstrated by Inoguchi et al in 1974.[10] They produced electroluminescent devices and ran them more than 20,000 hours at high-brightness levels up to 1000 fl (3400 candela/meter^2)without degradation. The encapsulating feature of the dielectric films protecting the active layer is no doubt partly responsible for the long life.

An attractive feature of ACEL is the extreme nonlinearity of the brightness voltage curve coupled with high peak brightness. This feature allows a large number of lines to be addressed, without crosstalk, in a simple matrix fashion before the display becomes too dim. Peak brightness of several thousand foot lamberts is readily attainable making displays of several hundred lines practical. A major disadvantage of ACEL devices is the high capacitive reactance (Xc) that must be driven and the relatively low efficiency of light generation.[23] This Xc together with high voltage requirements leads to a high cost for the drive electronics. The extreme ruggedness and excellent viewability of ACEL displays makes them very attractive for certain applications such as for military devices.

Vacuum Fluorescent

A vacuum fluorescent display consists of a matrix-addressed triode structrure in a glass enclosure. A schematic of a vacuum fluorescent display is shown in figure 8. When positive potentials are applied to a grid lead and to a phosphor-coated anode lead the phosphor at the intersection will glow and nowhere else. Thus multiplexing is very easy in vacuum fluorescent devices. The manufacture of large, uniform high-resolution structures in the vacuum envelope is very difficult, however, and limits both resolution and cost. The display is a strong competitor in the medium size display market due to its high brightness and wide viewing angle.[26] Color will be available, at a loss of resolution, by the use of red, green, and blue phosphor strips.

Projection and Light Valve

In the past few years there has been considerable development in projection television displays. Two basic types are being investigated. One type is direct CRT projection using either three tubes or a single very bright shadow mask tube.

Several manufacturers are producing these systems in the $3000 range for use in home entertainment at a screen size of 3 to 6 feet (approximately 1 to 2 meters). Brightness has improved dramatically and resolution today seems fully compatible with standard 500 line NTSC TV.[8] Brightness has been acccomplished with very high voltages (up to 50 kV) and improved light gathering optics. Future developments are likely to be rather less dramatic, however, and the system performance is probably not compatible with displaying 1000-line high definition TV.

Another type of projection system uses a medium to gate the illumination from a very bright light source called a light valve. General Electric is the dominant supplier in this area. In the GE system an electron beam deposits charge on a thin oil film causing the film to ripple. The projector uses an incredibly novel schlieren optical system to transform the ripple pattern into a full color projection image at high brightness and high resolution. The system can project a 1000 lumen image at 800 line resolution but costs $80,000.[24] The device is commonly used to project closed circuit sporting events in auditoriums and has become quite popular. Improvements are underway to increase resolution and reduce system cost. Other light valve systems under development use an electron beam or light-addressed liquid crystal target as the means to form images. It is felt that light valve systems will increase their market dramatically by lowering system cost and with the market need presented by high definition TV.

References

[1] Amano Y, Yoshida K, Shionoya T, Yokono S, (1982) "New DC plasma display panels and their applications," *Displays,* Vol. 3, No. 4, pp. 187-191.

[2] Apperly N, Pleshko P, Pearson K, Pierre E, Sherk T, Hairabedian B, Bradney F, Foster R, (1984) "Design of a plasma flat-panel large-screen display for high-volume manufacture," *Displays,* Vol. 5, No. 1, pp. 21-31.

[3] Denham D, Murch J, Meyer B, Singer M, (1984) "Autoconvergence enhances high-resolution display," *Electronic Imaging,* Vol. 3, No. 1, pp. 30-34.

[4] Dewey A, Anderson S, Cheroff G, Feng J, Handen C, Johnson H, Left J, Lynch R, Marinelli C, Schmiedeskamp R, (1983) "A 64 million PEL liquid-crystal-projection display," *Society for Information Display Technical Digest,* Vol. 14, Los Angeles, CA 90049, pp. 36-37.

[5] Franzen N, (1983) "A quadrupole scan-expansion acceleration lens system for oscilloscopes," *Society for Information Display Technical Digest,* Vol. 14, ibid., pp. 120-121.

[6] Goede W, (1978) "Flat-panel displays: A critique," *IEEE Spectrum,* Vol. 15, pp. 26-32.

[7] Herold E, Morrell A, Law H, Ramberg E, (1974) "Color Television Picture Tubes," *Academic Press,* NY, pp. 42-129.

[8] Hochenbrock R, Rowe W, (1982) "Self-converged three-CRT projection TV system," *Society for Information Display Technical Digest,* Vol. 13, ibid., pp. 108-109.

[9] Howard W, (1981) "Electroluminescent display technologies and their characteristics," *Proc. Society for Information Display,* Vol. 22, pp. 47-56.

[10] Inoguchi T, Takeda M, Kakihara Y, Nakata Y, Yoshida N, (1974) "Stable high-brightness thin-film electroluminescent panels," *Society for Information Display Technical Digest,* Vol. 5, ibid., pp. 84-85.

[11] Janko B, (1979) "A new high-speed CRT," *Proc. Society for Information Display,* Vol. 20, No. 2, pp. 55-56.

[12] Janko B, Franzen N, Sonneborn J, (1983) "CRT architecture with meshless scan expansion," *Society for Information Display Technical Digest,* Vol. 14, ibid., pp. 118-119.

[13] Kasahara K, Sakai K, Okada Y, Yanazisawa T, Matsumoto S, Hori H, (1983) "A 220×180 element MOS-LCD for 2 inch picture displays," *Proc. 3rd International Display Research Conference, Japan Display, '83,* Lewis Winner, Coral Gables, Florida, 33134, pp. 408-411.

[14] Kazan B, Knoll M, (1968) "Electronic Image Storage," *Academic Press,* NY, pp. 225-230.

[15] Kemtz A, Von Willisen F, (1976) "Nonemissive Electro-optic Displays," *Plenum Press,* pp. 9-24.

[16] Leskovar B. (1977) "Microchannel plates," *Physics Today,* Vol. 30, pp. 42-48.

[17] Maloney T, (1978) "Self-scan imaging display panel," *IEEE IEDM Technical Digest,* pp. 198-200.

[18] Morozumi S, Oguchi K, Yazawa S, Kodaira T, Ohshima H, Mano T, (1983) "B/W and color LC video display, addressed by poly Si TFTs," *Society for Information Display Technical Digest,* Vol. No. 13, ibid., pp. 156-157.

[19] Morrell A, (1983) "Future development of cathode ray tubes," *Proc. 3rd International Display Research Conference, Japan Display,* ibid., pp. 264-267.

[20] Odawara K, Ishibashi T, Kinuzawa K, Sakurada H, Tanaka H, (1980) "An 80-character alphanumeric liquid crystal display system for computer terminals," *Proc. Society for Information Display,* Vol. 21, pp. 79-83.

[21] Pleshko P, (1979) "AC plasma display technology overview," *Proc. Society for Information Display,* Vol. 20, pp. 127-130.

[22] Sobel A, (1977) "Gas discharge displays: The state of the art," *IEEE Trans. Electron Devices,* Vol. Ed 29, pp. 835-847.

[23] Takahara K, Kawada T, Yamaguchi H, Andoh S, (1983) "A refresh addressing technique for thin-film EL panels," *Proc. 3rd International Display Research Conference, Japan Display '83,* ibid., pp. 578-581.

[24] True T, (1979) "Recent advances in high-brightness and high-resolution color light value projectors," *Society for Information Display Technical Digest,* Vol. No. 10, ibid., pp. 20-21.

[25] Uchida T, (1981) "Bright dichroic guest-host LCDs without a polarizer," *Proc. Society for Information Display,* Vol. 22, pp. 41-46.

[26] Uchiyama M, Masuda M, Kiyozumi K, Nakamura T, (1982) "High resolution vacuum fluorescent display with 256×256 dot matrix," *Proc. Society for Information Display.* Vol. 23, No. 3, pp. 163-168.

[27] Williams H, (May '83) "Liquid crystal television - here at last," *Electro Optics,* pp. 55-57.