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A Preliminary Study of Flat-Panel Displays

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ABSTRACT

This paper presents six display technologies that might be of future value in a spacelab workstation. Some have been developed to the point where they could be used as a computer display while others have not. The display technologies studied are electroluminescents, light-emitting diodes, gas plasma, liquid crystal, electrochromic, and electrophoretic. An explanation of each mechanism is provided along with the state-of-the-art development.

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Introduction and Objective

The display that is portable or that requires more than a 26 inch diagonal screen will require something other than a cathode-ray tube. Firstly, the CRT's are heavy because of the thick glass needed to maintain the vacuum. Another problem with CRT's is the high voltage power source required to accelerate the electron beam. And, lastly, they are awkward and take up space due to the length of the electron gun.

The six flat-panel technologies in production now that might replace the CRT are plasma, liquid crystal, electroluminescent, vacuum fluorescent (VF), electrophoretic, and electrochromic display panels. VF has not been able to keep up with improvements in CRT's. And it will be another year before the last two mentioned are in the running. This paper will look at the first three mentioned. The objective is to collect information about displays that will be useful in making a display selection for spacelab.

Electroluminescent Displays (EL)

The basic means of operation of EL is not as well understood as is that of other display technologies. The AC or DC powder and AC or DC thin film configurations are based as much on experimentation as on theory. In the displays industry, single-crystal EL is called LED. Work by Professor R. Evrard at the University of Liege in 1980 and recorded by Professor F. Williams in the Journal of Luminescence volume 23, in 1981 made strides toward understanding high-voltage AC thin-film ZmS: Mn EL configurations. Theoretical work by Professor A. G. Fischer still holds for the ZmS: CuS powder configuration.

Three major types of mechanisms used in displays are:

TYPE I - Bipolar alternating double-injection luminescense, demonstratable with AC powder ZmS: CuS, or the Fischer Model.

TYPE II - Hot electron impact ionization of activator, demonstratable with AC thin-film ZmS: Mn and DC powder ZnS: CuS phosphors or the Chen and Krupka Model.

TYPE III - Memory effect in AC thin-film ZnS: Mn phosphors first reported by Yamauchi et. al. (1974) and described by Onton and Marrello.

AC Thin Film EL

The following configuration has been proven to have long life, high luminance, and video display capabilities: phosphor (ZmS: Mn) sandwiched between dielectrics (Y_2O_3, S_iO_2, and Al_2O_3), then these are sandwiched between the row electrode (Al), and the column electrode (Indium-tin oxide) on the viewing side, and then these are sandwiched between a seal material and glass on the front viewing side. When an electric field is set up between the electrodes, the thin-film emits light.

From -269^{o}C to about 77^{o}C only minor changes are observed in the luminance and electrical characteristics of ZmS: Mn AC thin-films. One problem with thin-films is the occurance of pinholes. The pinhole breakdown failure rate of weak thin-film sandwiches is accelerated at higher temperatures. Weak thin-film dielectrics will conduct and cause the panel to heat. High operating temperatures due to internal heating causes rapid panel deterioration. On the other hand, the insensitivity of AC thin-film ZmS: Mn panel enhances its potential range of applications.

When properly fabricated a luminance vs voltage hystersis has been demonstrated with the AC thin-film EL using ZmS: Mn phosphor. The hysteresis can be used to freeze a frame on the panel. And images frozen on the panel can be read to a memory device.

Failure mechanisms that have slowed the development of AC thin-film EL displays are electrical breakdown, film delamination, and electric field-induced chemical reactions. Electrical breakdowns in the form of pinhole electrical arcs are unavoidable. These burnouts, less than 50 micrometers in diameter and stable, are to be expected and tolerated. Two pinhole breakdowns per square inch is achievable, and if they do not destroy the pixel or line, this is allowable.

The Coulomb forces can tend to separate the thin-films at the time of external field polarity reversal. This can occur when air is included as a background gas during dielectric dispositions. Water entrapped in the film ionizes causing delamination. This delamination can be controlled by using state-of-the-art techniques for improved adhesion.

The field-induced chemical reaction is oxidation of the aluminum electrode. It can be stopped by blocking the source of oxygen with an oxygen-free material.

Sharp has reported the life of ACTFEL at over 20,000 hours in a controlled environment. They have also reported a typical 30% reduction in luminance in large panels after 10,000 hours. Aerojet Electrosystems report no pixel failures out of 900 pixels during 12,000 hours of operations.

AC powder EL is made from ZmS and ZmS phosphor, and is activated with supersaturated copper sulfide and other coactivators such as Mn, Cl, and Ag for color. AC powder EL devices are primarily used for transillumination of panels, keyboards, and other displays such as AC plasma panels and twisted-nematic liquid crystals. They can be used anywhere a continuous low-illuminance film is needed.

Of the powder EL sandwiches, the DC is more readily matrix addressable than is the AC. The DC powder EL using ZmS: Mn has been used commercially in 80- and 256-character readout displays and automative panels.

The technical maturity of AC thin-film EL is behind that of gas plasma and of the CRT in accumulated production volume and production experience, user experience, and associated test data. Also, the basic knowledge of the EL physical phonemena is immature compared with that of gas plasma and CRT. However, these are being overcome due to advantages of TFEL.

Although not as bright as gas plasma (GP) displays, EL display panels find their place between liquid crystal display (LCD) panels, which cannot rapidly display large amounts of data, and very expensive plasma displays, which show as much data as a CRT, but cannot produce a gray scale for video.

LCD's have difficulty providing a high-quality six-inch-diagonal screen while EL panels run into difficulty around 15 inches. Planar systems predict that EL will dominate the 6-inch to 15-inch flat-panel market.

The integration of an EL display with a portable computer ($8,000 mostly for the panel) demonstrated that a good flat panel display could be produced for personal use and that manufacturing processors need to be developed to reduce the cost of the EL panel.

The thin-film EL panels consist ZmS doped with Mn placed between two insulating dielectric layers. This is then sandwiched between vertically oriented and horizontally oriented electrodes. A black layer provides high contrast for the panel, and the entire thing is sealed in glass.

Only three companies are engaged in large scale production of thin-film EL -- Sharp of Japan and Lohja of Finland (U. S. subsidiary: Finlux, Saratoga, CA) and Planar Systems. Planar is a spin-off from the company Tektronix, Inc. when Tektronix decided to close down flat panel R&D, three engineers continued the work, backed by the company as a silent partner with a major interest. In October of 1984 Planar was awarded a $1.5 million contract by the Army for the development and manufacture of multicolor EL flat panel displays. These will be used in military ground vehicles.

In first quarter of 1985 the first 640 x 440 pixel EL display monitor, the largest of its kind was demonstrated at the Society for Information Display conference. This full-page panel, offering a resolution of 60 lines per inch on an active display area of 6 x 10 inches came from Planar Systems, Inc.

Takashi, Ito, and Hikasa reported this year in the Journal of Applied Physics a new multicolor ACTFEL device. A gate layer is deposited between layers of ZnS: ErF_3 and ZnS: SmF_3. This is placed between layers of dielectrics, Y_2O_3. And this is placed between the electrodes. The emission color of the device varies continuously between red and green with the driving voltage or frequency.

Gas Plasma Displays (GP)

Why have plasma displays been so successful? To achieve intrinsic matrix addressability, the display element must have a nonlineas relationship between luminance and applied voltage. Practically no light is emitted from the gas discharge element for voltages below the firing voltage. A lifetime of 50,000 hours is not uncommon in plasma displays. And the failure is not catastrophic but is a slow degradation in display quality. The pixels that have been discharged the most become the weakest. It is common for a plasma display to outlast the entire life of the product. GP has good brightness and luminance, although not as good as in some other display technologies. Plasma displays compete favorably since they can achieve high contrast ratios because the display media is transparent. The basic structure of GP is only slightly more complex than that necessary for an array of X and Y electrodes on glass. Plasma displays are usually as rugged as the sheet of glass of which they are made. This rugged structure makes large-area plasma displays practical. They are available on the market with resolutions as high as 100 lines per inch and as large as one meter diagonal panels.

Another plus for GP is its tolerance to harsh environments and temperature extremes. To exhibit a reasonable lifetime, plasma displays must be hermetically sealed with a high-temperature glass frit seal. Hence GP will operate in high-humidity or in the presence of reactive gases. For many plasma displays the limiting factor on the operating temperature is determined by the drive circuits and not the display. The characteristics of most AC plasma displays can be considered invariant with temperature.

The capacitance of GP displays is low compared to thin-film electroluminescence. Therefore, the drive circuits require less current capability, a distinct advantage when using thin-film conductors.

A full range of color can be achieved by depositing phosphors in the GP display. Flat color TV displays with sixteen inch diagonals and excellent picture quality, have been made in laboratories. The brightness is not as good as that of a CRT. Plasma displays, as do all flat-panel displays, have low volume, slim profile, and freedom from distraction.

The most important reaction of a gas discharge is ionization. When an electric field is placed across the gas, electrons from a primer cell are accelerated by the field. If after reaching an energy of 21.6 ev the electron collides with a neutral neon atom, an electron can be ejected from the atom. Characteristic light is emitted from the ion and there are now two electrons being accelerated to a collision. These two electrons can then go on to create two more ionizations and so on, resulting in an avalanche. The number of ionizations occuring in an avalanche is in the range from ten to three-hundred.

Some electron will not have enough energy to knock an electron out of the neon atom but will have enough energy to knock an electron up to a higher energy level (excited level). This excited electron will soon fall back down to the ground state of the atom and emit a characteristic photon of light.

Not all excited states of the neon atom will allow the electron to drop to a lower state and emit a photon of light. One that does not is called a metastable state. Thus themetastable neon atom wanders around carrying extra energy. If the metastable neon collides with an argon atom the extra energy is enough to ionize the argon causing its characteristic light to be emitted. The mixture that gives the largest amount of ionization per applied volt was found by F. M. Penning in 1937 to be Ne plus 0.1% AR. This is called a Penning mixture. Other Penning mixtures include neon plus small amounts of Xenon, Krypton, or even certain noninert gases. Argon-neon mixtures are commonly used in plasma displays.

Gas Plasma (GP) is the only flat-panel technology of the top six that currently offers performance equal to or better than that of the CRT. There are three types: AC, DC, and hybred. The DC plasma shows aging at temperatures below $0^{o}C$ and above $50^{o}C$. The AC-plasma panels operate over a wider temperature range, from $-40^{o}C$ to $+85^{o}C$. The DC-plasma has a typical life of 30,000 hours while that for AC-plasma is longer. The GP displays, also, have a 120^{o} viewing cone.

The DC-plasma is less expensive because it is easier to drive but, at the same time, it has no inherent memory and must be refreshed. The AC-plasma need not be refreshed. IBM now leads the AC-plasma technology with its 22 x 20 inch and 25,000 pixel display.

The major manufacturers of DC-plasma displays are Fuji Electronics America (Torrance, CA), NEC Corporation, OKI, and Matusushita.

The hybrid method combines the best features of both AC- and DC-plasma technologies. It is being developed by Plasma Graphics Corporation (Warren, NJ). The reduced number of drivers limits the use to handling static data, like word processing. Dynamic displays are not possible.

Liquid Crystal Displays (LCD)

For a century now some organic materials have been known to melt into a stable, ordered liquid state before melting again at a higher temperature into an isotropic liquid state. The molecules that make up the ordered liquid are rigid-crystal state can be indicated by an array of cigar-shaped rigid molecules. Customarily the direction the molecules point is indicated by a unit vector called the director.

In another phase of liquid crystal the elongated molecules lie in planes, parallel to the plane, and with the director of each plane rotated with respect to adjacent planes. This circular-staircase structure is characteristic of the chalerleric phase, that derives its name from the fact that some derivatives of cholesterol molecules exhibit this phase.

Another liquid-crystal phase is called smectic. The characteristics of the smectic phase is elongated molecules in layers usually with the molecular axis perpendicular to the plane. A typical melting sequence of a smectic could be from crystalline to smectic, to nematic, to isotropic liquid.

The dominant technology tends to be the twisted nematic mode. The mechanism for this mode is described later in the report.

Some researchers claim that by 1986 the liquid crystal displays will overtake plasma displays as the unit popular flat-panel graphics display. There are three types of LCD's: Twisted-Nematic Field Effect (TNFE), Active Matrix, and Smectic LCD's.

Commonly used in calculators TNFE LCD's consist to two glass plates with rows and columns of transparent conductor lines. The LC mixture is sandwiched between the two plates. The front plate has a transparent polarizing filter. The back plate has a reflecting polarizer, oriented at 90° to the polarizer on the front plate.

When no current is applied to the conductors, the long LC molecules form spiral staircase shaped structures, joining the two glass surfaces. These molecules give light passing through them a 90° twist. However, when current is applied, the crystals line up, and let pass through unaffected.

The result is that these cells with no current applied reflect ambient light, and appear light-colored. This is because light passing through the face plate is polarized in one direction, get twisted 90° by the LC, allowing it to pass through the back plate polarized, which reflects it forward again. As it passes through the LC again, the light gets a second 90° twist, reorienting it to its original position, and thus allowing it to pass out through the polarizing face plate.

Conversely, cells with current applied absorb ambient light, and appear dark. In this case, light is polarized in one direction by the front face plate, and passes through the aligned LC unaffected. When the polarized light reaches the back plate, the reflective polarizer of which is oriented 90° opposite to that of the front plate, it is blocked. Therefore, light is not reflected back, and the cell appears significantly darker than surrounding cells.

One difficulty with LCD's is the slow response time of the LC's as they reorient themselves. Another is the viewing cone angle is about 40°. Low brightness and poor contrast are other problems. One solution to the latter two problems is the Active Matrix LCD's. Manufacturers have deposited active, non-linear elements at each pixel. This creates a matrix with a driver at each display point. Two devices used to provide the active matrix are thin-film-transistors and metal-insulator-metal diodes. This causes sharp rise in contrast and the viewing cone jumps from 40^{o} to at least 90^{o}.

Crystal vision (Sunnyvale, CA) has developed a smectic LC that is solid at room temperature, but liquid at slightly higher temperatures. In this case the data are literally frozen in place and the LCD does not need to be refreshed. This simplifies the electronics, and provides a much larger display. However, display time is slow and drivers needed to handle the heating requirements are expensive.

Crystal vision, Inc. has developed a LCD that has 640 cols x 256 rows and can be used in a 25 line x 80-char format. Although the writing speed is about 2,000 chars/sec, it special cases it can approach 1,000 chars/sec.

The display consists of two parallel glass plates separated by about 145 micro-meters which is filled with a smectic liquid crystal and dye mixture. The front plate has transparent indium-tin oxide column traces running vertically. The back glass has textured mirror-finished metalic row heating traces running horizontally. A pixel is created at the intersection of each of the 640 cols and 250 rows, for a total of 16,000 pixels.

In this dichroic display, the cigar-shaped, liquid crystal molecules take up dyes along their length. When the molecules lie parallel to the viewing surface, the dyes are visible. When the molecules are perpendicular to that surface, they are invisible. In the non-excited state, the molecules are parallel to the viewing surface and the color appears (the background). When excited, they stand up on end and become transparent, and a negative image is produced.

The metalic electrode on the back glass plate serves both as an electric-field source and as a heater for the dichroic LC; it also serves as a reflector. To generate a display, the electrode first melts the liquid crystal. The the electrodes field aligns the dichroic molecules. Finally, when the electrode is turned off the LC refreezes, capturing the display.

Vacuum Fluorescent Display (VF)

VF displays a number of advantages over other emissive technologies, partially for small alphanumeric displays. VF displays are five times brighter than any plasma type display. Brightness for VF is between 150 and 200 footlamberts compared to between 30 and 45 for gas plasma. The display characters can be in a wider range of sizes for VF than for GP displays. VF displays also operate over a much wider temperature range than GP; from -40^{o}C to +85^{o}C for VF. For GP, the best range will operate from $0^{o}C$ to $+55^{o}C$. As with GP, the viewing cone for VF display is 120^{o}.

In formation content flat panel displays are usually either limited by electronic or physical/manufacturing constraints. VFD's are limited by the latter, while multiplexing large arrays is not difficult, manufacturing large grids is. Consequently, the largest VFD's available are 16 square inches.

For low information displays, VFD's offer low cost and low power requirements. As a result they are competing successfully in the market with LCD's and GPD's. There is a large market developing for VF displays in the automative industry for clocks, radios, and dashboard displays. They are attractive and can be produced in various colors.

Electrophoresis

Electrophoresis has been around for some time, but is only in the last several years that interest in its use as a display technology has grown. In electrophoretic displays, particles migrate from a cathode to an anode, or vise versa. Titanium-dioxide particles, that are white, are microencapulated in an organic material that can be changed. These white particles are placed in a black suspension. If a voltage is placed across the electrodes, the positively-charged titanium dioxide will migrate toward the negatively charged anode producing a white image. The anode must be optically transparent, since it is the front plate and the viewing surface. A problem about to be solved is that of keeping the particles in the suspension stable.

Two companies working on electrophoretic displays are Exxoi Enterprises (San Jose, CA) and North American Philips (Briarcliff Manor, NY). However, the product probably won't be ready for another year. When ready the product will be a passive display similar in performance to LCD's. But it will not have polarizers as LCD's do and so will have greater contract and viewing angle.

Electrochromic Display

Electrochromic displays are material that change colors when exposed to an electric field. When the field is removed, the color remains, applying a field of reversed polarity changes the color back again.

Electrochromic displays based on tungsten trioxide change from colorless to deep blue. Daini Seikasha (Tokyo, Japan) has developed a display based on this material, which was used in Seiko digital watch display. More recently, Rockwell

International reported on an electrochromic display using diphthalocyanines that can display a variety of colors - including shades of blue, orange, and purple - depending on the voltage applied.

Early use of the electrochromic displays will be in instruments and aircraft cockpits readouts. Although every material responds differently, response time tends to be a problem for most of them, limiting the technology to lower information content applications. Most companies involved in electrochromic displays stress the need for more research.

Conclusion and Recommendation

If black and white will suffice for the display, then electroluminenscent (EL) has some definite advantages like weight, size, and voltage required. If color is needed, the shadow mask CRT is needed.

DISPLAY UNITS

PARAMETER	(SHUTTLE)	E.L.	PLASMA	L.C.D.	SHADOW MASK
Viewable size	5 x 7	5 x 6 1/4	8 x 8	4 x 9	11" x 14"
Power	90	20	40	.15	130
Temperature	-28° to 54°C	-55° to 71°C	-30° to 63°C	0° to 50°C	-30° to 55°C
Pressure	8.3 PSIA	0 PSIA	Problem	Problem	8.3 PSIA
Weight	27	10	55	3	35
Highest Voltage	14 KV	160 V	150 V	5 V	25 KV
Readability	Sunlight	Sunlight	Room	Sunlight	Sunlight
Brightness (F1-L)	55	30	30	N/A	30
Viewing Angle	100° Cone	140° Cone	120° Cone	40° Cone	140° Cone
Resolution (Characters)	51 x 26	80 x 58	85 x 51		132 x 55
Spec	Space (Norden)	Battlefield (Hycom)	Submarine (Interstate)	None	Aircraft

TABLE I -- IBM SUMMARY DATA

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