THE PLASMA DISPLAY PANEL—A DIGITALLY ADDRESSABLE DISPLAY WITH INHERENT MEMORY *

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INTRODUCTION

Despite a growing interest in graphic communication in computer systems and a rapidly developing computer technology, the cathode ray tube remains the most useful of available display devices. Its limitations, however, are serious, particularly in systems with many display terminals. Other than phosphorescence it has no memory. Its images, therefore, must be regenerated continually, and to avoid flicker they must be transmitted at video bandwidths. Furthermore, as an analog device in a digital environment the cathode ray tube requires signal conversion circuits that are both complex and expensive. Other limitations such as high voltage and space requirements are less serious but are still significant.

The Plasma Display is a new device that, in contrast to the cathode ray tube, retains its own images and responds directly to the digital signals from the computer. Its resolution is comparable to that of cathode ray tube displays, and in addition it can be interrogated by the computer. It also seems likely that images can be drawn directly on the display panel by means of a light emitting pencil. Although this device is at an early stage of development some of its system properties are already known, and others can be estimated. The purpose of this paper is to discuss, on the basis of these properties, the role that the Plasma Display could fill in future computer systems. A brief description of the display is also included. More detailed accounts are available,[1-3] and a discussion of the display from a device standpoint will be published elsewhere.

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DESCRIPTION OF DISPLAY

The display is constructed of three pieces of flat glass as shown in Fig. 1. Through the center piece a matrix of small holes is drilled, and on one surface of each outer piece a grid of transparent gold conducting strips is vapor deposited. The glass sheets are typically 0.006 inch thick and the holes in the center piece are about 0.015 inches in diameter. In assembly the grids are on the outer surfaces of the panel, they are orthogonal to one another, and the strips are in registration with the holes. Each gas cell, shown in the section view of Figure 2, is thus surrounded entirely by glass except at the interfaces between the glass sheets. Through these thin gaps air is evacuated and a gas is admitted to the cells.

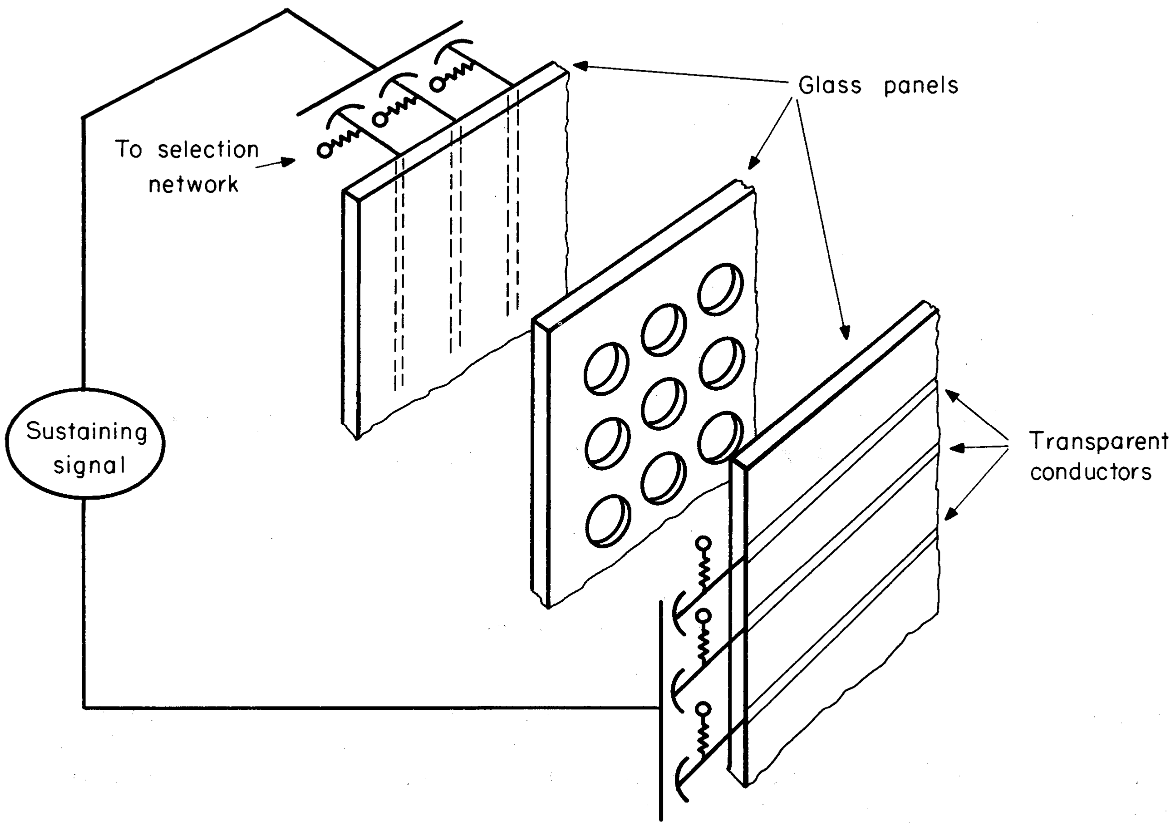

Figure 1. Assembly of plasma display panel.

If an alternating voltage across a cell exceeds the firing voltage, a discharge is established which develops rapidly to a glow. At the same time the flow of charges to the insulating walls reduces the voltage across the cell. When this voltage becomes too low to maintain the discharge, the glow is diminished and the discharge itself is quenched. Measurements of the current in the cell and of light radiated from the cell have shown that with appropriate gases this entire process takes place in from 50 to 75 $\times$ 10^{-9} seconds. During the following half cycle the voltage caused by the wall charge adds to the voltage due to the external signal. Once the first discharge has been established, therefore, the voltage required from the exciting signal to establish succeeding discharges is less than that required in the absence of wall charge. In fact, if the flow of charges to the walls is just sufficient to neutralize the field that exists within the cell at the time of firing, the ratio of these two voltages is 2:1. At intermediate voltages, therefore, the cell is bistable. In the "zero" or "off" state the peak cell voltage is insufficient to create a discharge. In the "one" or "on" state a brief discharge occurs once each half cycle of the sustaining signal. Figure 3 shows a photograph of the light pulses together with the exciting signal. The time scale is 1 microsecond/division, and the sweep is triggered repeatedly during the 1/25 second exposure time.

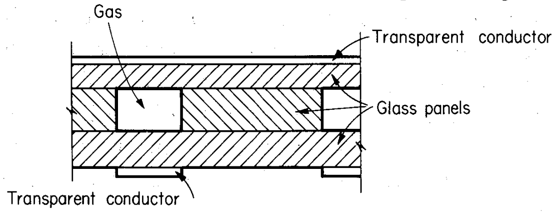

Figure 2. Gas discharge cell.

The memory actually resides in the wall charges,

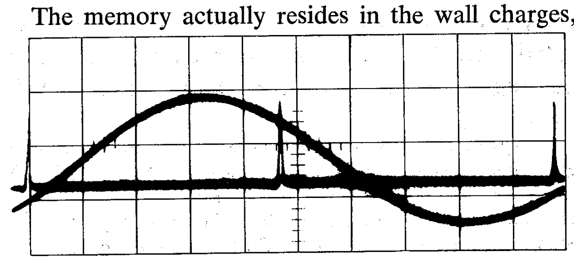

Figure 3. Light pulses and exciting signals.

and it is often convenient to describe the device processes in terms of the wall voltages associated with these charges. In the "off" state, for example, the wall voltage is, ideally, zero. In the "on" state the wall voltage alternates at the exciting frequency, combining once each half cycle with the external voltage to fire the cell. Changing the state of a cell is essentially a matter of controlling the changes in the wall voltage.

Except when the pattern on the display is changed a balanced alternating signal, either sinusoidal or pulsed, is always applied across the two grids. This sustaining voltage is in the bistable range, and the voltages on all lines in a grid are equal. During this time the pattern remains on the display and there is no communication between the computer and the display. When the state of a cell is changed an appropriate balanced voltage is applied across the two electrodes that intersect at that cell. Across the remaining cells affected by these electrodes only one half the voltage appears. This reduced voltage is within the bistable range and does not change the states of these cells. Write signals from the computer cause the states of selected cells to be changed in sequence from "off" to "on." Erase signals which change states from "on" to "off" control either single cells in sequence or rectangular blocks simultaneously.

If the peak voltage across two conductors that intersect at an "off" cell is raised above the firing potential the cell will be driven to the "on" state. In the process the wall voltage, starting at essentially zero, oscillates between two changing positive and negative values until after several cycles these limiting voltages reach stable values. The external voltage, however, need only exceed the firing voltage once to initiate the process.

The short transition time cannot be attributed to charge leakage along the glass surfaces. In fact charge can remain on the walls for many milliseconds. We have observed, however, that both the intensity of the discharge and the amount of wall charging increase when the slope of the exciting signal increases. The differential charging during the first few discharges after the state is changed drives the process to equilibrium.

The state of a cell can also be changed from "off" to "on" by combining a slowly varying control signal with the sustaining signal. This slow write procedure allows the use of high impedance switching circuits, and is appropriate to several important uses of the display.

Several procedures, both fast and slow, have been used to change the state of a cell from "on" to "off."

The computer not only can write and erase patterns on the display, but it can also test the state of any cell by applying the sustaining signal to only the electrodes that intersect at that cell. If the sustaining signal is applied to only one pair of intersecting conductors only that cell responds to the signal. If the cell is "on" it emits light pulses that are detected by a single photocell at the back of the display panel. If the cell is "off" it does not emit light. The states of all other cells remain unchanged since the wall voltages do not change appreciably in this time interval. If the sustaining signal is pulsed rather than sinusoidal the read signal is timed to appear between pulses. By sequentially testing selected cells the computer can read information from the display.

The initiation of a gas discharge requires both a sufficiently high voltage and the participation of charged particles. In normal operation electrons are provided as slowly diffusing metastable atoms hit the walls. In "on" cells large numbers of metastables are created during each discharge. In "off" cells they can be created by conditioning pulses that cause discharges about one hundred times less frequently than in the "on" state. If these conditioning pulses are removed and if the exciting voltage across both grids is raised above the firing potential, the observer can, in principle, write directly on the display by means of a light emitting pencil. If he illuminates a group of cells, photo electrons released from the walls initiate the discharges that turn the cells "on." The procedure works very well for a single cell. It has not, however, been tested for the important case when selected series of cells are to be turned on in the neighborhood of many cells that are to stay off. Unless each cell is well shielded optically from its neighbors the first cell to turn on may initiate a wave of state changes that will quickly turn on the entire display.

We are at present studying the properties of small displays with a linear cell density of 40 cells/inch. The photograph, Fig. 4, shows one of these displays in which the sustaining signal is connected to a 3 $\times$ 4 matrix. In the pattern seven cells are in the "on" state and five are in the "off" state. The actual distance between adjacent cells is 0.025 inch. We have also constructed single cells as small as 0.006 inch

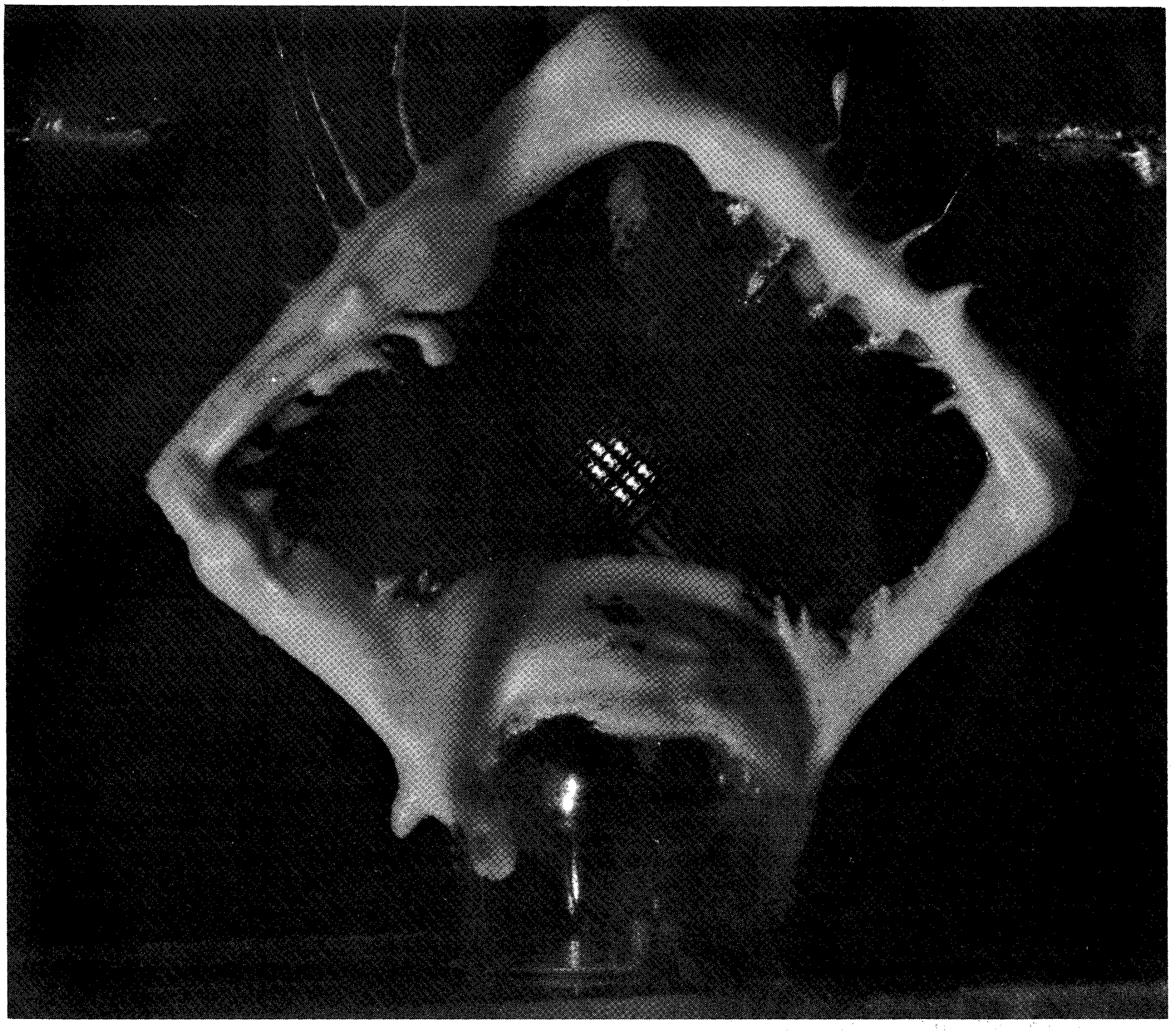

Figure 4. Experimental plasma display.

and we believe that linear densities in excess of 100 cells/inch (10^4 cells/inch^2) can be achieved.

To the authors' knowledge no earlier memory displays have utilized pulsed discharges and their associated wall charges. These discharges in larger cells, however, have been observed by a number of investigators, and the influence of the wall charges on the development of these discharges has been understood for many years.[4-6] Loeb and El Bakkal in particular have observed that with argon in large cells (diameter = 8 cm) a sequence of pulse discharges could be maintained at 60 cycles/second by a voltage less than that required to initiate the sequence.[6]

SYSTEM PROPERTIES

The development of the Plasma Display Panel was motivated by the anticipated needs of the PLATO computer-based education program at the Coordinated Science Laboratory of the University of Illinois.[7] The experimental classroom which has been developed as part of this program consists, at present, of twenty student stations, each with a television display and a keyset connected to a central computer (CDC 1604). In addition twelve terminals are available for use at remote locations. For each station the computer transmits signals to a storage tube memory and selects a photographic slide that contains the appropriate text for that student. The storage tube and the slide are then scanned simultaneously and the superimposed signals are transmitted to the cathode ray tube.

Within several years there may be similar systems with several hundred stations, and it is not unreasonable to predict that in the future thousands of people in classrooms and even in homes will communicate simultaneously with a central computing facility.

Advances in computer technology have been so rapid that present computers with their high speed, large memory, and steadily decreasing cost per unit operation, are adequate for this kind of service. Display technology, however, has not kept pace with these advances. The TV-storage tube displays, of course, perform well in the PLATO system, and other CRT devices are used successfully in information retrieval systems. However, no display device is now available that performs well, and is sufficiently inexpensive for use in these large systems. If efforts to develop the Plasma Display are successful, this device should meet both performance and cost requirements.

Admittedly, the specific needs of a teaching system emphasize the importance of some properties of a display, and are less demanding of others. Nevertheless, we believe that these needs are similar to the large systems being developed for banks, air line reservations control, and for corporate and university administration. In all of these systems the resolution requirements are at most those met by standard television, information rates are low, and low display cost is imperative. In the remainder of this section we discuss the properties of the Plasma Display (Table I) particularly as they govern the use of this display in these systems. We also discuss briefly its use in the more specialized systems where both high resolution and high data rates are important.

For its use in the display terminals of a teaching system the property of the Plasma Display that most simplifies system design is its inherent memory. Because its images do not need regeneration from an auxiliary memory, information flows from the computer to the display only when the images are changed and then at rates dictated by the uses of the display. Transmission lines can be specified to match these rates, which are much less than the limiting rates acceptable to the display itself.

Experience dictates that in this service a character writing rate of 140 characters/second is completely satisfactory. This corresponds to a point writing time of 358 microseconds/point, hardly taxing even the slow writing rate on the display. At 30 characters/line and 20 lines/page, an entire page can be written in about four seconds. If the display is equipped with a character generator that sequences the selection of points according to a seven bit code, the corresponding information rate is 1000 bits/second, a rate that is easily accommodated by voice grade telephone lines. Point plotting for maps, graphs, and diagrams is slower. If, for example, we assume a 512×512 raster and specify each point independently by 18 bits, only 55 points are plotted each second. Useful curves, however, can still be plotted in a few seconds. Furthermore with the addition of mode detecting hardware these rates can be increased by a factor of two or three.

Let us assume that each of 3000 remote displays simultaneously receives information at 1000 bits/second from the computer. The information rate on all lines together is then 3×10^6 bits/second, which for a computer with a 48 bit word length calls for one word of output every 16 microseconds, well within the capability of a modern computer. If these 3000 stations are in a single community, each one can be connected over a telephone line to a central distribution point which is in turn connected through a video channel to the computer.

In a teaching system some of the information on the display represents comments or numerical answers entered directly by the student. In some cases he wishes to rewrite all of the information on

Table I

System Properties of Plasma Display Panel

Property	*Performance*
Cell Density	40-100 cells per inch
Memory	self contained, charge storage on walls
Addressing Mode	digitally addressed
Erase Modes	complete erase, character erase, point erase
Writing and Erase Rate—Slow Mode	10^4 points per second
Writing and Erase Rate—Fast Mode	10^6 points per second
Full Screen Erase Time	5 microseconds
Brightness	comparable to cathode ray tube
Power Input	100 microwatts per point lit

the screen; in other cases he wishes to rewrite only part of the information. Two erase processes have therefore been provided in the PLATO system. One erases the entire screen. The second selectively erases a single character. It would be desirable to extend selective erase to specified points but because of the interaction in the storage tube between the electron beam and the stored charge this cannot now be accomplished. In the Plasma Display every point is addressable. Full erase, and both character and point selective erase, can therefore be implemented.

The resolution requirements of a teaching system are easily met by the Plasma Display. With a cell density of 1600 cells/inch^2, a 512×512 raster corresponds to a display that is 13.8 inches on each side. This provides both adequate viewing area and resolution better than that provided by the television display in the PLATO system.

Although information rates and resolution requirements may be the same in many of these systems, this may not be true for display size and shape. A bank teller, for example, may want to see the name, code number, and account balance of a depositor. Or a purchasing agent may request the name of a company, its quotation on a bid, and perhaps a record of previous business transactions. A strip display with 512 columns but only 64 rows might be entirely appropriate for these applications. For the corporate board room, or for the military command room, much larger displays are indicated.

In this connection it is important to draw another comparison between the Plasma Display and the cathode ray tube. The density of points on a cathode ray tube varies roughly with the size of the tube and the number of resolvable points remain about the same. On the other hand, the number of resolvable points in the Plasma Display can be increased simply by adding more cells. The cell size can also be varied over a range of at least ten to one, but the limits are not yet known. These properties of the display allow considerable freedom in planning large wall displays.

An additional property of the display that may be useful in special applications is that it can be fabricated with curved surfaces.

There are, today, an increasing number of applications that will fully exploit the resolution and fast writing properties of the Plasma Display. The display of dynamic processes, for example, requires video signals, and for the production of high quality still photographs and motion picture films high resolution is a necessity. Since this service is usually provided by high quality cathode ray tubes whose images are regenerated from magnetic core memories, we compare the appropriate properties of the Plasma Display directly with those of the cathode ray tube.

The maximum writing rate of commercial electrostatic CRT display systems is about 200,000 points/second. This limit is set by the settling time of the digital to analog converters and of the circuits that position the electron beam. If, to avoid flicker, we stipulate 20 frames/second as the minimum frame rate, 10,000 points can be displayed. If the pattern on the screen represents a dynamic process, such as wave motion, and if it changes every frame these rates are actual information flow rates. If, on the other hand, the pattern is stationary these rates are used only to provide the greatest detail possible in a flicker free display.

The storage tube television display of the PLATO system has no flicker problem but its resolution is not as great as the directly addressed electrostatic tube. Magnetically focussed and directly addressed cathode ray tubes offer greater resolution, but at the expense of writing speed.

Because of the inherent memory of the Plasma Display, the number of points in a stationary pattern is limited only by the number of cells in the raster. The limit is much lower when dynamic processes are represented by rapidly changing patterns. If a writing rate of one point/microsecond can be maintained on large displays, a pattern containing 50,000 points can be completely changed at the rate of 20 frames/second.

Two useful features of present cathode ray tube display systems are that information on the display is available to the computer, and that by means of a light pen a programmer can manipulate patterns on the display. These features are also present in the Plasma Display, but it appears that each can be extended. The display itself functions as an auxiliary memory that can be consulted by the computer, and to the ability to manipulate patterns may be added the ability to draw patterns directly on the screen.

A comparison of quality in the two kinds of displays is difficult because the character of the displays is different. In the Plasma Display the number of addressable points and the number of resolvable points are the same. This is not true in the cathode ray tube. It is now possible to address a raster of

4096 × 4096 points, but the number of resolvable points is at best about 2000 × 2000.

At present we cannot realistically consider cell densities greater than 100 cells/inch for the Plasma Display. Thus, the display must be 20 inches wide to match the best cathode ray tube resolution and 40 inches wide to provide 4000 resolvable lines. Except for large displays, the cathode ray tube can provide a picture of higher quality. Furthermore, it is possible to draw continuous lines on the cathode ray tube, and in photographic work this is sometimes important.

In the preceding discussion we have not considered any of the very active research on electroluminescence, or on electron-hole recombination in semiconductors. We believe, however, that it is appropriate to call attention to a different type of gaseous discharge display in which the basic cells are direct current discharges.[8,9] This display has some of the same advantages as the Plasma Display. To remove addressing ambiguities, however, it seems necessary to isolate the cells from one another by inserting a resistor in the connecting lead to each cell.[9] The resulting fabrication difficulties appear to limit the achievable cell densities.

CONCLUSIONS

We must emphasize again that the Plasma Display is in an early stage of development. We are working with small matrices, and we have only recently transmitted signals from the computer to change cell states. Nevertheless we know of no fundamental obstacles that will frustrate this development, and if the development is successful the Plasma Display will fill an important role in the computer technology of the near future.

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