Plenary : Surface Discharge and 3-Electrode ac Plasma Displays

G. W. Dick
Lucent / Bell Laboratories (retired)
Murray Hill, NJ. USA

1. Introduction

Following the invention of the ac plasma display by Bitzer, Slottow et al at the U. of Illinois in 1966, Owens Illinois Co. developed and manufactured the first practical, twin-substrate, plasma panels throughout the 70's. These panels as shown partially in figure 1 were the primary flat panel, full-page displays of the period. They were not very bright however, and used very bulky, expensive, drive electronics. Such terminals cost roughly ten times the cost of a CRT terminal. Many groups including those at Bell Labs, Fujitsu, and NHK worked on the brightness and electronics issues. Some of this was directed at single substrate or surface discharge designs which are optically more efficient. This direction at Bell led to the study of the 3-electrode per pel panel in the early 80's. Full-page versions of this design were produced in a pilot line for roughly six months. At that time a government anti-trust investigation of AT&T was underway which led to a divestiture decision (against AT&T) . This in turn led to a decision by AT&T to stop all on-strategic business units including displays in August 1984. Some work on color applications was briefly continued as will be discussed in the following section.

2.Single Substrate (Surface Discharge) ac Plasma

The Twin Substrate ac plasma display shown in figure1 used top and bottom cell plates which were essentially identical with a 90 degree rotation to allow X-Y addressing. Sustain drivers supplied alternating power pulses to all pixels simultaneously by the top and bottom conductors. Individual cell writing and erasing were also supplied selectively on the same conductors hence the electronics decoupling problem. Transparent dielectric coatings over the electrodes were typically screen printed vitreous solder glasses. These were then over-coated with vacuum-deposited MgO to obtain high electron emission and also to provide protection from ion bombardment in the discharges. Conductors were generally opaque, gold or silver screenings or thin-films of Cr-Cu-Cr to obtain the necessary low impedance sustain conduction. Spacing between plates of approximately 0.1mm.is important in determining operating voltages and cross-talk margins. This spacing was obtained with short glass fibers placed throughout the panel. Thus the panel was relatively easy to fabricate with no precise top/bottom plate alignment required in spite of glass shrinkage etc. due to firing of the layers. It is however, not optically efficient due to the self-shielding of the glows by the electrodes. It was also not adaptable to color display due to the difficulty of placing phosphors around the pixels where they would be sheltered from ion bombardment and early failure. Color mixing from cell to cell could also be a problem due to the open cell geometry. In addition, due to this structure, charge spreading and cathode glow spreading is also possible and results in electrical crosstalk as drive voltages are increased.

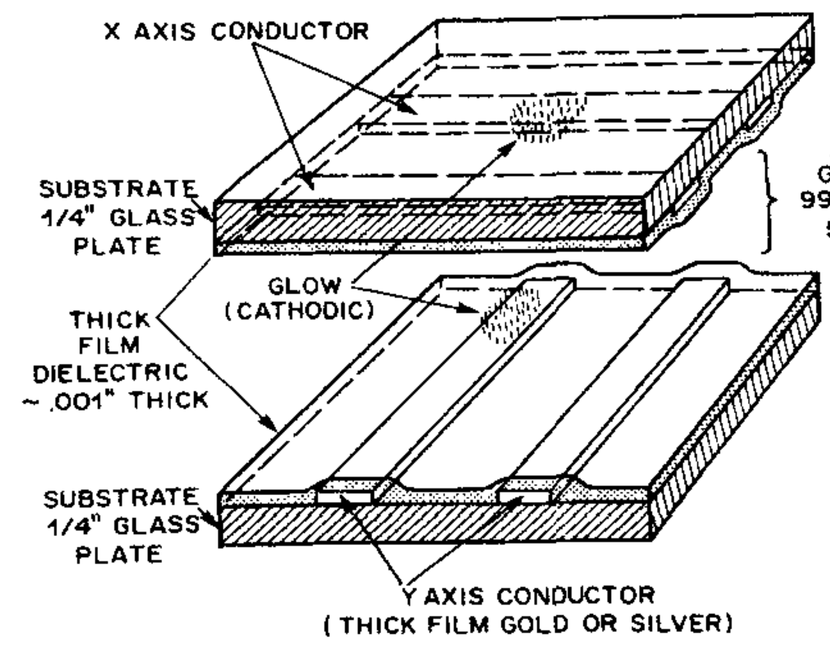


Figure 1. Twin Substrate Panel

Placing both X and Y electrodes on the bottom substrate leaving the top plate clear of dielectric does improve luminosity. The structure can then be termed "Single Substrate" as shown in figure 2. Both discharge alternations,ie. due to positive and negative sustain discharge phases, occur on the wall surfaces over the electrodes. Typically the bottom electrode when acting as cathode produces a larger area glow [1] ie. greater spreading. This has been avoided by the use of a metallic or capacitive vias to equalize or localize the wall capacitances or by the use of floating, field controlling plates placed between pixels.[2] The major problem with these single substrate techniques lies in the multlayer fabrication requirement. Using screen-printed thick films a hierarchy of solder-glass melting points is required to avoid the middle conductor layer sinking wth shorts resulting. This could be avoided by the use of all thin films, however with several microns of dielectric thickness required to limit discharge current, this becomes expensive. In addition the open cell construction still results in tightened drive margins due to crosstalk as well as possible color excitation crosstalk.

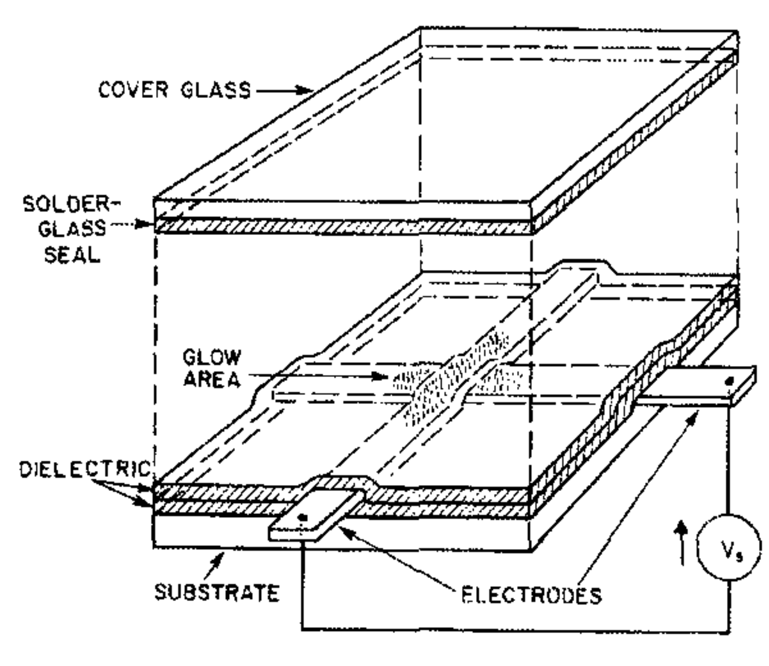


Figure 2. Single Substrate Panel

3. Early Three Electrode per pel Designs

The three-electrode per pel design was initially proposed for monochrome Ne – Ar computer displays to reduce the cost of data drivers. The X-axis sustain current of these panels was about 25 milliamp peak per line while the data (write) current was a hundredth of this. I.C.'s to handle only data were much smaller while the X-axis sustain current could be handled by a few power FET's. This so-called common sustain drive could be carried by row aligned conductors parallel to the normal Y-axis scanning and sustain conductors. Glow stopping between pixels was provided by dielectric, thick-film ribs as shown in figure 3 . The ribs were deposited on the substrate to achieve better glow or ion etc. blocking between pixels regardless of rib height uniformity or smoothness. Heights achieved were typically about 75 microns with 3 or 4 screenings.

In operation as in figure 3 a selected cell X1, Y2 receives a typically 80 volt data pulse Vwx and a y-line scan pulse Vy2 of minus 80 volts to write the cell. Following this a write transfer pulse Vw2 could, although not necessarily, be used to transfer electrons from the cover wall to the common sustain electrode wall at the written pixel. This usually assisted the write operating margins. Then the sustain pulses on Se, So, and all Y electrodes would carry on the discharge alternations over the substrate Selected single pel erase pulses could be provided as the previous write pulses were, or as indicated, a single erase pulse applied to a scan electrode such as Y2 could erase the full line.

The early production model display of 400 by 640 lines was 25 by 32 cm. by 3.2 cm. deep including power supplies, drivers,etc. Its average brightness was 38cd/sq. meter (188 peak) and luminous efficacy was about 0.3 lm/watt [3]

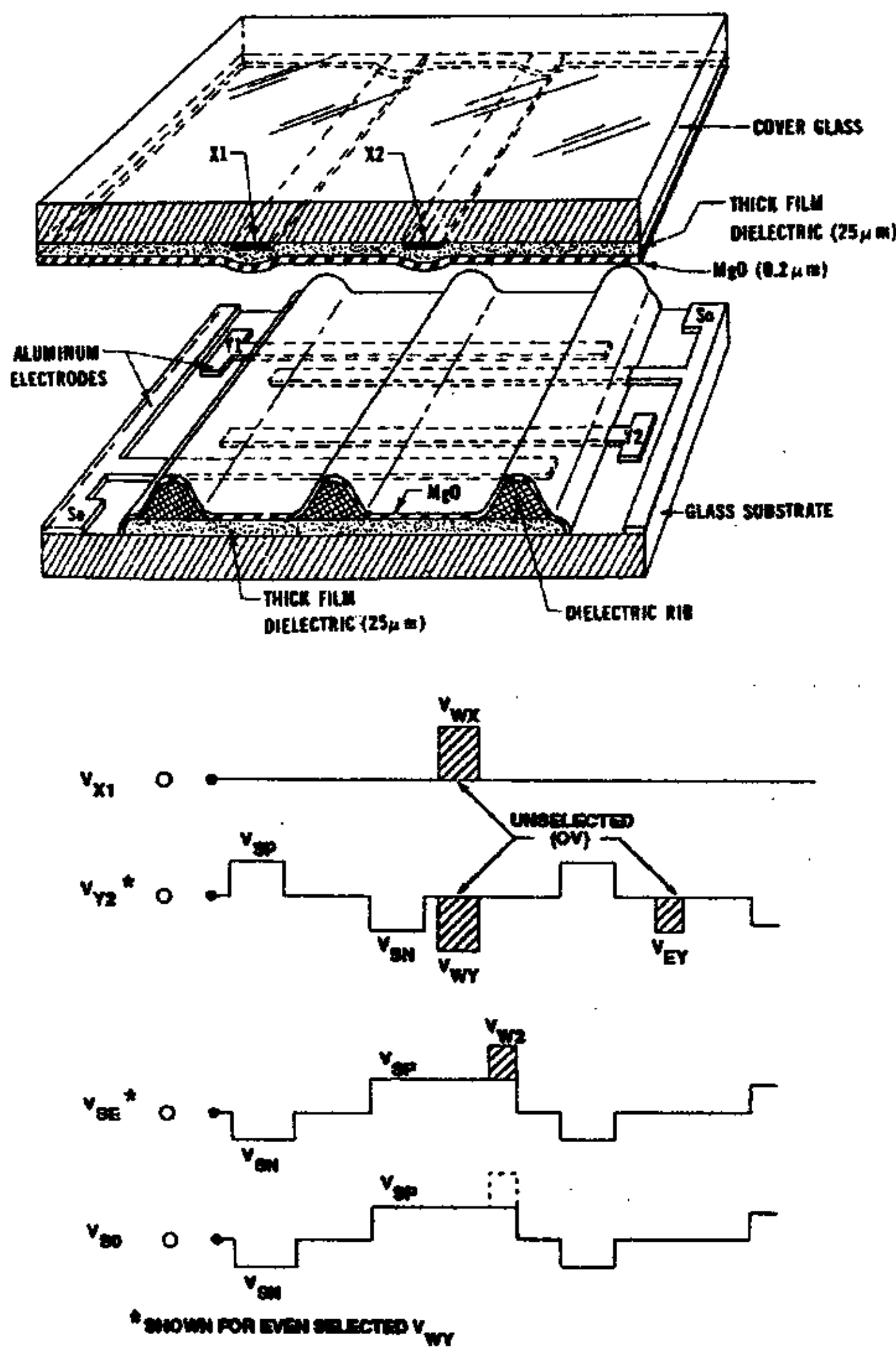


Figure 3. Early 3 Electrode ac Plasma

4. Early Three Electrode Color Panels

Early work showed the rapid aging that occurs with He – Xe panel mixtures due to the high mobility of the Xe ions. Thus Ne – Xe gas mixtures were used with about 1% Xe levels. These could be driven with the standard IC's at the time. (higher levels required higher drive voltages) Essentially standard 3-electrode panel structures were used with three-color phosphor dots screen-printed on the cover over the dielectric. The phosphors were then excited by the 147 nm. Xe emission in transmission rather than the now common reflection mode. i.e. transmission as in CRT cathodo-luminescence. A 192 by 384 experimental panel was demonstrated operating from a PC with game programs but without gray scale. Its brightness in white was 77cd / sq. m. at 26kHz sustain frequency. Luminous efficacy was 0.5 l / watt Aging tests showed no significant sustain voltage or luminance changes for 20,000 Hrs.

5. More Recent Progress (1986 to 2003)

For color applications operating the plasma cell in reflection mode rather than transmission appears desirable. It permits, for instance, additional emission of visible radiation from side walls of the ribs.

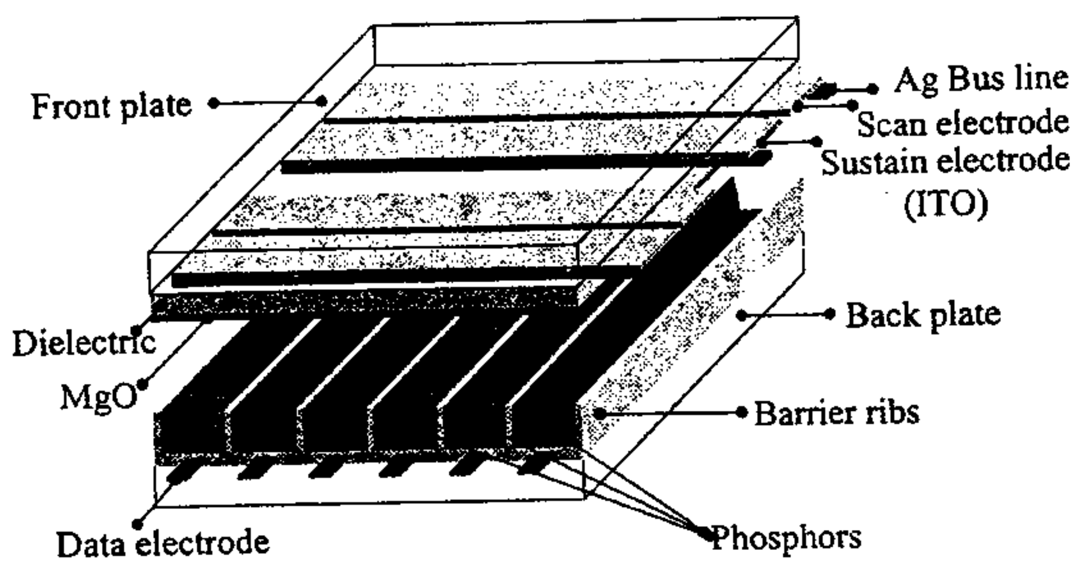
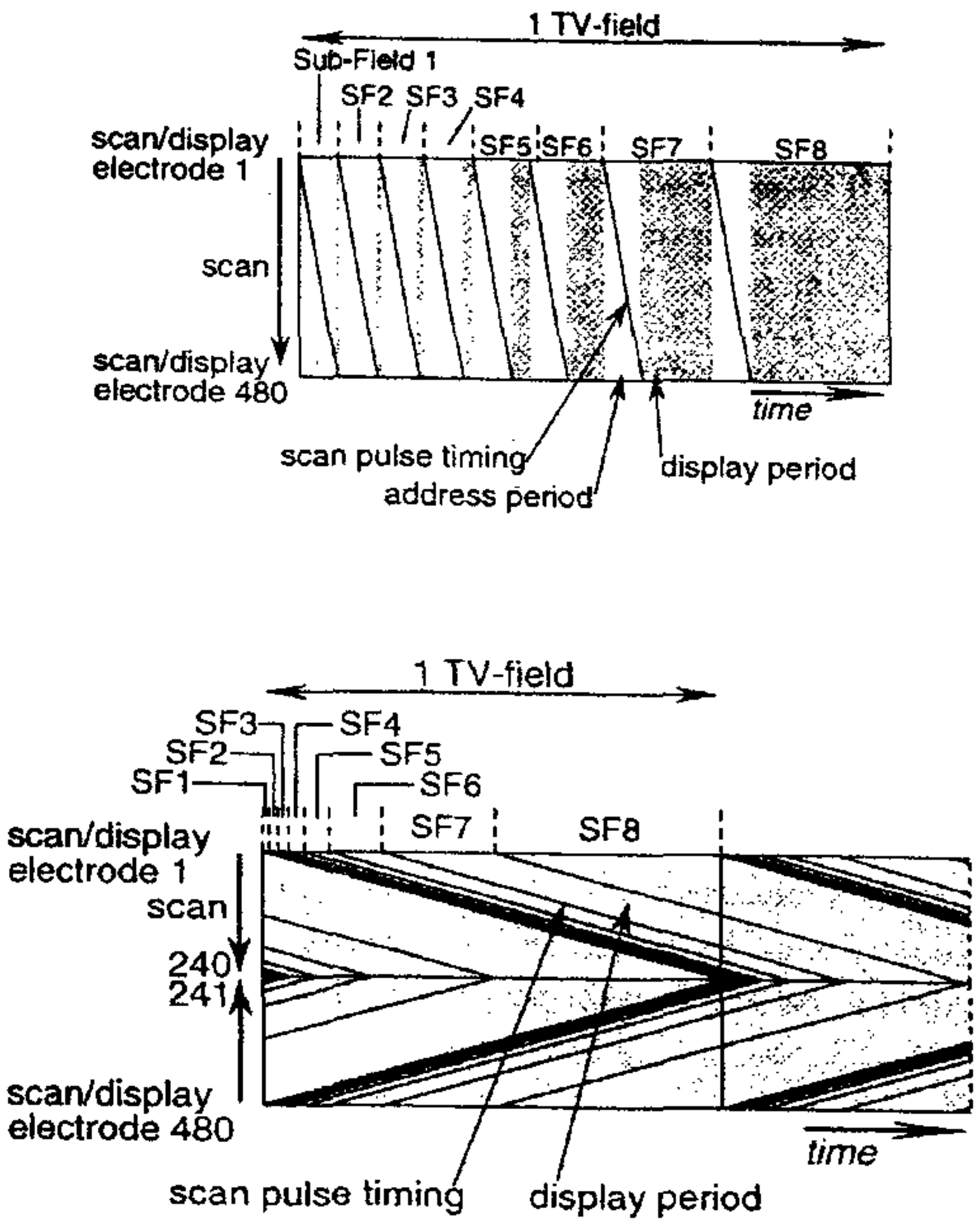


Figure 4 Modern 3-Electrode Panel – with straight ribs

Thus the three electrode panel as currently used is reversed with respect to the viewer or front side as shown in figure 4 . Now the data electrodes, dielectric, and phosphor layers occupy the back or bottom plate with the ribs also deposited there. The front, top, or viewer-side contains the parallel sustain, and scan high current electrodes and the wall dielectric / MgO layers. To permit high luminance the two electrodes are usually made of SnOx or ITO transparent films with current-carrying narrow metallic bus electrodes placed at the outer areas of the discharges. Operation of the cell is the same basically as described for the early panel however, transfer pulses are not used. The basic drive scheme used in most PDP's for gray scale applications is the so-called " Address Display Separation" (ADS) method[4]. In this the TV. scanning frame is subdivided into 8 or 10 sub-fields each with a separate writing and sustaining period for the whole panel Each sub-field presents a different sustain interval duration for the whole panel as shown by the shaded portions in figure 5 (top).Thus various levels of brightness can be generated by any pixel depending on how many of the sub-field states the pixel is "on" for. During the addressing interval for each sub-field all rows of the panel must be sequentially scanned.



. Figure 5. Gray Scale Scan Methods

Top ADS method [4] Bottom AWD method [6]

It is important therefore that rapid write addressing be achieved for each line e.g. for a 480-line panel if 2 microseconds are required per line about 1 millisec. is then required for each sub-field address period. Thus for 10 sub-fields more than half the frame time of 16.6 milliseconds is used for scanning leaving only 6.6 milliseconds for sustaining (about 40% emission duty-cycle). To minimize the address time and to achieve reliable writing a special reset or set-up pulse is used before each sub-field scan. This also produces UV. and visible emissions from all pixels thereby reducing dark ambient contrast levels. A slow-rising set-up pulse [5] has been found to avoid this by creating a low-current positive- resistance discharge which provides excited priming particles, and a well defined wall charge state but very low emission. Another gray scale drive scheme which is actually older than the above is called the " Address-While-Sustain" (AWD) scheme [6]. In this, the addressing operation for all sub-fields is merged with the sustain pulses to avoid the duty-cycle loss of the ADS scheme. In addition a nearly constant cease time is provided between a priming pulse and each sub-field write pulse on each line (many separate priming pulses) to obtain faster writing. Figure 5 (bot) illustrates the timing for a 480line panel which operates with a 96% duty cycle. This panel is scanned simultaneously over the top and bottom halves to double the scan time available per row. This also doubles the number of data drivers and halves the scan drivers. The voltage of the data drivers was reduced to 20volts from 130v due to the constant cease time.

One problem with gray scale generation by time division , with binary-weighted sub-fields as in figure 7 is the transient generation of false contours where the image or the viewers line of sight is moving. It is most noticeable for heavier weighted portions of the image for example for changes from the 128th level to the 127th. There is then a discontinuity in the emission in time which is much greater than the average intensity change. This shows up only when there is movement and has been termed MPD or Moving Picture Disturbance. Several methods have been used to correct the problem such as adding sub-fields to smooth out the time discontinuity, or redistributing the sub-fields.[7,8].

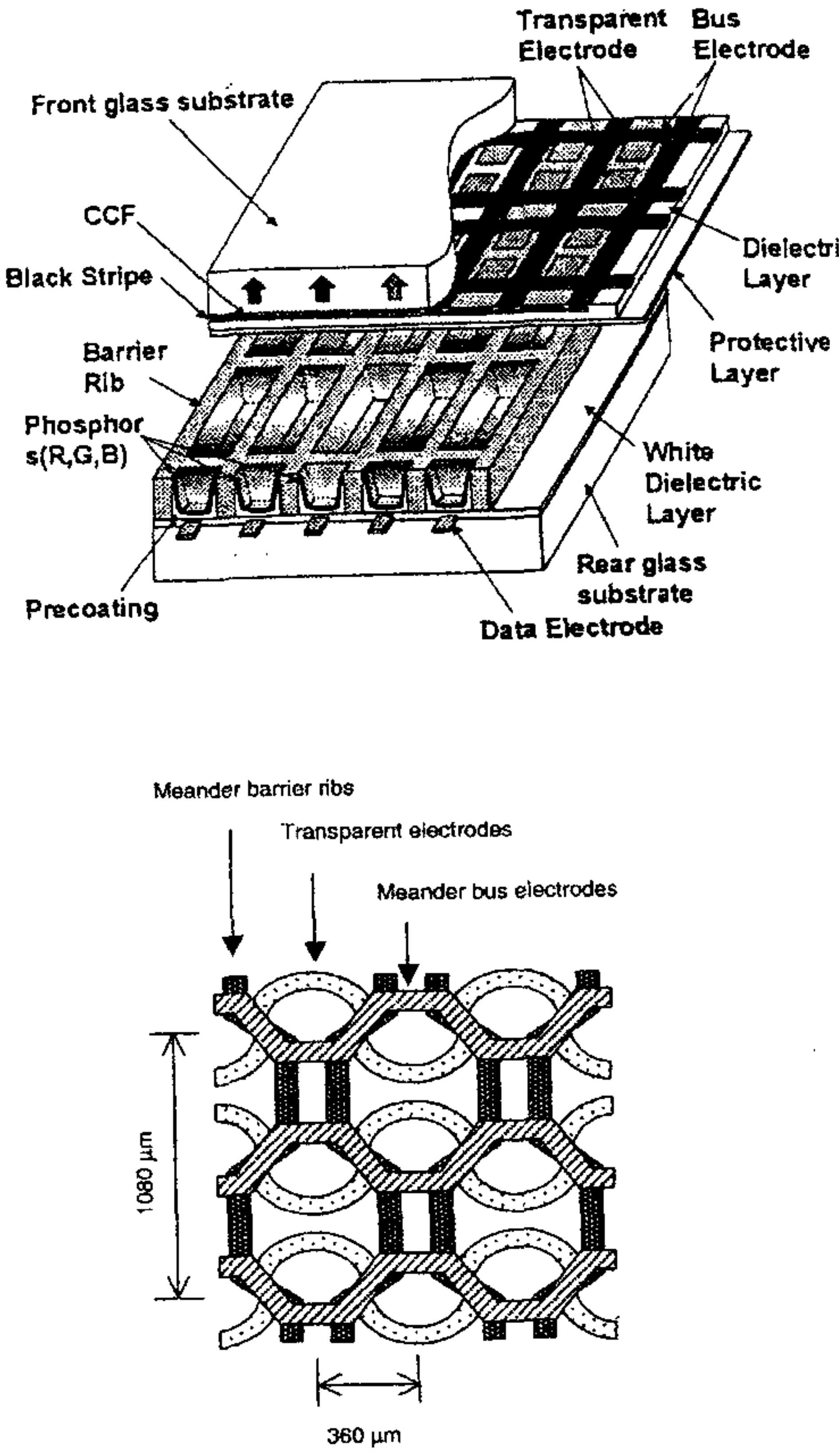


Figure 6. Waffle shaped Ribs

Top – NEC rectangular [9] Bot – FHP Meander [10]

Good white-light efficiency is of major importance especially in large PDP's where input powers of 300 to 600 watts can often be required. Present-day efficiencies of three electrode ac panels are typically about 1 lm/watt compared to CRT's which show from 2 to 5 lm/watt. Two main avenues are being taken with considerable success in correcting this. One is to optimize cell geometry to increase active cell area and improve optics, while retaining similar gas mixtures and driver requirements. The other approach retains some of the cell simplicity for ease of manufacture, but to increase Xe percentage levels. In the latter some drive modifications are also incurred to limit voltage requirements. One cell redesign approach is shown in figure 6 (top), by an NEC Corp. 61 inch panel which uses shaped transparent sustain electrodes in a fully isolated pixel .ie. a waffle shaped barrier rib structure. [9] The shaped electrodes can extend the glow area vertically without crosstalk due to the end walls. This large display requires 660 W for a full white picture. Another structure mod by FHP displays Ltd. uses the so-called "Delta" arrangement of RGB cells, and a meander structure for the ribs and sustain electrodes, as in figure 6 (bot). This provides a wide 6-sided discharge volume connected vertically to neighbors by a narrow, high threshold channel. Bake-out, pumping, and back-fill is then accommodated. With this experimental structure efficiencies of 3 lm/W at a white luminance of 200 cd/sq. meter could be obtained with 4%Xe – Ne mixtures. Using a waffle rib structure, T-shaped electrodes, and a higher Xe (~15%) gas mix Pioneer Corp. have shown 1.8 lm/W efficacy and a peak luminance of 900 cd/sq. meter on a 50-inch panel. Power consumption is quoted at 380 watts.[11]

A delta structure with a broad rectangular enclosed cell termed (SDR) has been analysed using 3-dimensional simulations and ray-optic calculationsat Samsung and Sejong University. [12]. Results confirm that a faster discharge with lower average current is obtained compared to the long stripe-geometry waffle cell [9] and with a wider optical aperture better efficiency results.

The increase in sustain and firing voltages in higher Xe content gas mixtures appears to be due in part to reduced secondary emission from the cathode by the lower energy Xe ions (9.82 ev.) versus Ne ions (18.96 ev.) Recent experimental results from Philips [13] show that with some cell modifications, but typical ADS addressing, increasing partial Xe pressure from 3.5% to 13.5% and total pressure from 650hPa to 800 hPa, increases efficacy from 1.6 lm/ W to 4 lm/W. Luminance is also increased to 3500cd/sq.meter at 225volts sustain, from 710cd/sq. meter at 175volts for the standard pressure etc. An important cell design improvement in this study was also to reduce the wall capacitance per unit area which results in increased discharge speed.

6. Materials and Processing

Electronics cost rather than materials has always been the main issue with PDP econonomics. IC. costs,despite the higher voltages, are improving steadily with improved circuitry, better on-chip isolation (dielectric type) and chip-on-glass (coming?) Larger panels also do not necessarily require more drivers and more packaging, interconnects, and signal processing. Glass cost on the other hand does increase with panel area however even with high strain point types such as PD200 at 4X the cost of soda-lime, this is not a major factor.

A major factor however is the cost of rib fabrication, [14] and with some of the complex rib patterns, the difficulty of plate assembly and alignment must be considered. The conventional screen-printed ribs require around 8 – 10 screen and dry cycles to achieve 150micron rib heights. Large panels require large printers and screens which stretch with use limiting their use to a few hundred panels before errors in registration above 20 microns occur. Alternatively very precise ribs can be fabricated by the sandblasting process in which a dry film sandblast resist is laminated onto a homogeneous green coating of rib material on the substrate. The unwanted lead glass is then removed and later reclaimed (or not). The process is subtractive and not very clean but produces accurate and smooth ribs. Another subtractive process, termed photo-casting, blends a photo-sensitive paste with the rib powder. This uses a photo-mask as an exposure pattern but often requires a few exposure-development cycles to produce the full rib height. The most recent process by 3M Corp. uses a flexible polymer mold which replicates the rib pattern. This is held onto the substrate while the rib paste is squeezed into the mold cavities and onto the plate. The mold is then removed and the ribs fired. Very accurate rib patterns and uniform heights are obtained with this inexpensive (relatively) process.

Other expensive processes such as MgO deposition, pump-out, back-fill, and sealing are relatively slow. ie. Pumping, sealing, baking, and cool-down require 10 to 11 hrs on large panels. Thus to get the required throughput from such a production line requires banks of ovens or multiple pumping carts and long, in-line ovens as in CRT production. The geometry of the flat panels is some benefit for building such equipment.

7. Conclusion

While the cost of PDP's is still too high for mass markets, the situation is fast improving. 42inch panels costing $100/inch in 2002 are now at $75/inch and forecast to reach $50/inch by 2005. (Samsung) Worldwide PDP forecasts show an increase in home-market units from 475 K units to 4389 K units in the same period. (Display Search 2003.03) Business units in that period should increase from 560 K to 1,227 K units. Despite the possible threat of 40 or even 50 inch AMLCD developments, plasma TV displays appear to have a secure grip on much of this market for at least several years.

8. Acknowledgment

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9. References

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