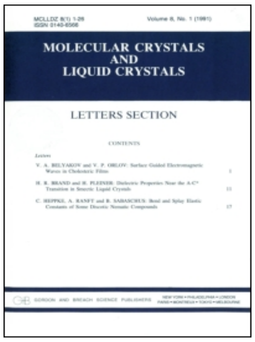


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# Study on luminous efficiency of AC plasma display panel with large gap between sustain electrode

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**ABSTRACT**

The luminance and luminous efficiency was investigated in new structure of AC plasma display panel with the large gap between the front electrodes under a high Xe gas mixture when adopting the proposed driving waveform. As an electrode was far from the other on the front plate comparing to the conventional structure, the driving waveform, especially in the reset and sustain period, should be modified. Therefore, during the reset period, the negative voltage was applied to the sustain electrode to produce the surface discharge between the scan and sustain electrodes. In addition, the sustain waveform was also modified to induce the surface discharge between the front plates after the triggering was made between the front and rear plates. As a result, when the modified driving waveform with the positive sustain voltage of 140 V and negative triggering voltage of −110 V during a sustain period applied to the panel with Xe gas mixture of 15% and the sustain gap of 500 um, the luminance of 340 cd/m$^2$ and luminous efficiency of 3.26 lm/W were obtained in the 42-inch AC PDP.

**KEYWORDS**

Luminous efficiency; large sustain gap; AC plasma display panel; driving waveform; gas mixture

## 1. Introduction

Alternate current plasma display panel (AC PDP) has been on the brink of a precipice in the current television market due to the low luminance and luminous efficiency compared with the other displays. However, AC PDP still has some merit such as a high speed response characteristic, a self-emission device, a cheap manufacturing cost, and so on [1]. One of the main reasons that AC PDP could not be popularized was low luminance and high power consumption, *i.e.* low luminous efficiency. If the luminous efficiency could be improved dramatically, the AC PDP could rise in the display market. In the previous works to improve luminance and luminous efficiency, the two studies had been suggested; one is to increase Xe gas mixture and the other is to use the very large sustain gap structure for producing positive column plasma [2, 3]. AC PDP has typically three electrodes – it is composed of two parallel electrodes on the front plate and one vertical electrode on the rear plate. The large sustain gap means the case of the long distance between two parallel electrodes on the front plate. If a high Xe gas mixture and a large sustain gap are used at the same time in AC PDP, the luminance and luminous efficiency will be increased sharply. However, the high Xe gas mixture induce increase

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in the entire driving voltages and the misfiring discharge is generated between the front and rear electrodes before the normal surface discharge is produced between two front electrodes when the conventional driving waveform is applied to the large sustain gap due to the long discharge path between two front electrodes compared to the conventional structure [4, 5]. Therefore, the new driving technique for the new concept of AC PDP is needed to minimize the rise of the driving voltages and prevent a misfiring discharge in the case of the large sustain gap.

First of all, the discharge firing voltage should be investigated at the AC PDP with a high Xe gas mixture and a new panel structure to design a new driving waveform. However, since the number of electrodes is three, it is impossible to measure the discharge firing voltage with the common way. Therefore, the Vt close curve method may be used by the measurement of the relative discharge firing voltage based on one electrode [6, 7]. The overall driving voltage will be set based on the measured the Vt close curve at the new structure. During a reset period, the positive rising ramp waveform is applied to the scan electrode due to the high discharge firing voltage between the two front electrodes – the scan and sustain electrodes – and the wall charge can be accumulated in a cell similar to the conventional case by the application of the negative square voltage on the sustain electrode [8]. In an address period, the address discharge is produced when the negative scan and the positive address voltages are applied simultaneously to the scan and address electrodes under the high positive bias voltage on the sustain electrode. The main role of the applied voltages during the reset and address period is the production of the stable plasma discharge in only selected cells [9]. During a sustain period, if the conventional driving method is adopted to the new structure, the misfiring discharge is produced between the front and the rear electrodes because the discharge firing voltage between the scan and sustain electrodes on the front plate is much higher than that between the front and the address electrodes on the rear plate.

In this study, the suitable value of the Xe gas mixture and the distance between the front electrodes is first suggested to improve the luminous efficiency, and Vt close curve is measured to investigate the discharge firing voltage among three electrodes. In addition, the new driving waveform during a sustain period is proposed to prevent a misfiring discharge between the front and the rear electrodes and to produce the stable sustain discharge in the new structure. The new driving method during a sustain period is divided into the driving waveform to make trigger discharge between the front and rear electrodes and that to make main discharge between two front electrodes. After the negative trigger voltage is applied to one electrode on the front plate and the plate discharge is produced between the front and rear electrodes, the positive sustain voltage is applied to the other electrode on the front plate for the surface discharge between two front electrodes. If there is no trigger discharge, any sustain discharge will not be occurred between two front electrodes. In order to prevent a misfiring discharge between the front and rear electrodes, the voltage difference between the front and rear electrodes should be applied at the inside of Vt close curve. Therefore, in this paper, the values of the voltage in the driving waveform are appropriately adjusted.

## 2. Experiment

### *2.1 Panel structure and specifications*

The cell structure for the large sustain gap in this experiment was shown in Figure 1. The 42 inch test panel deposited by the red, green, and blue phosphor was used where that has a Xe gas

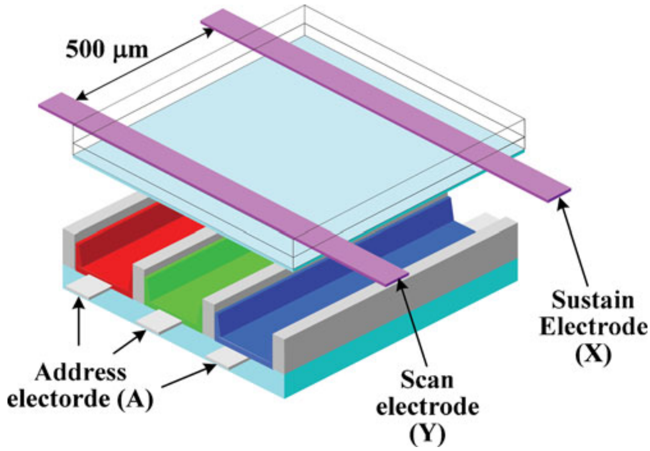


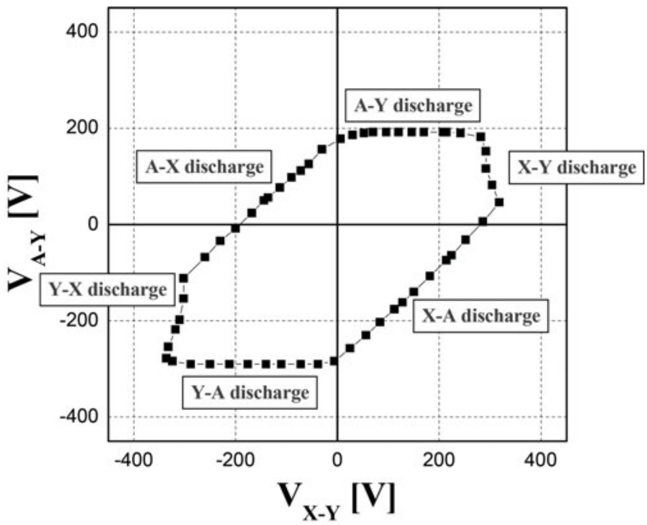

**Figure 1.** Structure of AC PDP with large sustain gap on front plate.

mixture of 15%. The sustain electrodes were only ITO-free bus electrodes and the gap between the two front electrodes (X and Y electrodes) was 500 $\mu$m. The width of the front electrodes (X and Y) was 100 $\mu$m, the thicknesses of the front dielectric layers were about 30 $\mu$m, the width of the address electrode (A) was 80 $\mu$m, and the height of the barrier rib was 80 $\mu$m. The panel specifications were listed in Table 1. On the front plate, the sustain electrodes gap means the distance between the X and Y electrodes and the width means the wideness of one electrode. On the rear plate, the address electrode width indicates the wideness of the address electrode and the height of barrier rib indicates the height of wall to separate each address electrode.

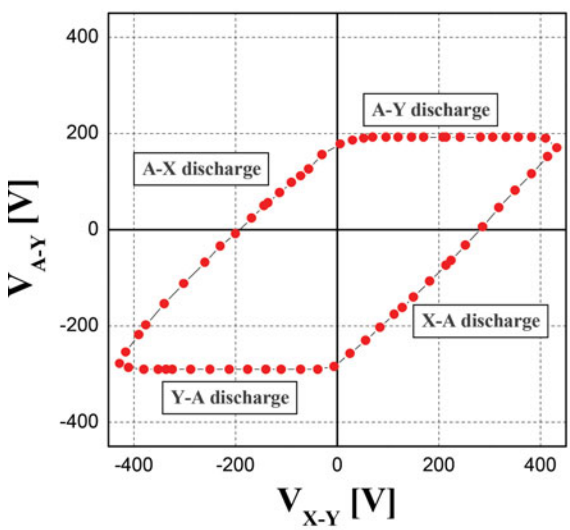
The Vt close curve was measured to confirm the discharge firing voltages and compare to the conventional structure under the new gas mixture and structure as shown in Figure 2. Figure 2(a) shows the measured Vt close curve in the conventional structure, whereas Figure 2(b) shows that in the new structure under the high Xe gas mixture. In Figure 2, the $V_{X\text{-}Y}$ on the horizontal axis indicates the threshold voltage between the X and Y electrodes based on the Y electrodes, whereas the $V_{A\text{-}Y}$ on the vertical axis indicates the threshold voltage between the A and Y electrodes based on the Y electrode. The typical Vt close curve shape in the conventional structure is a hexagon with six sides as shown in Figure 2(a). As the marked point is the discharge firing voltage, the inner region means a non-discharge region and the outer region means a discharge region. As shown in Figure 2(b), however, for the large sustain gap, the Vt close curve shape is parallelogram with only four sides, which indicates that the discharge between the X and Y electrodes cannot be produced directly because of the long distance between the X and Y electrodes. That is, this means that only surface discharge (discharge between the X and Y electrodes) without producing a plate discharge (discharge between the A and Y or the A and X electrodes) cannot be produced. In this sense, the trigger discharge between the front and rear plate should be needed to induce the production of the surface discharge between two front electrodes.

**Table 1.** Voltage levels applied to conventional and proposed driving waveforms in this study.

| Front | | Rear | |
|---|---|---|---|
| Sustain electrodes gap | 500 $\mu$m | Address electrode width | 80 $\mu$m |
| Sustain electrodes width | 100 $\mu$m | Barrier rib height | 80 $\mu$m |
| Thickness of dielectric layer | 30 $\mu$m | | |
| Gas mixture | | Ne (85%) - Xe (15%) | |




(a)




(b)

**Figure 2.** Measured Vt close curve in (a) conventional and (b) new structure.

### *2.2 Proposed driving waveform*

Figure 3 shows the proposed driving waveforms including the reset, address, and sustain periods for the large sustain gap structure with a high Xe (15%) gas mixture. During the reset period, the positive ramp reset waveform was applied to the Y electrode, while the negative voltage was applied to the X electrode so as to adjust the wall charges on the X electrode regardless of the large sustain gaps. The falling ramp waveform on the Y electrode and positive bias voltage on the X electrode redistributed the accumulated wall charge for the stable address discharge. When the scan and address pulses were applied during an address period, the address discharge was induced between the Y and A electrodes. While the address discharge

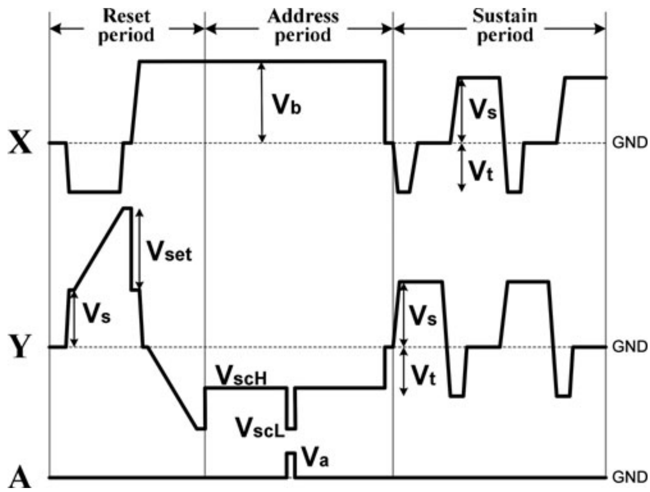



**Figure 3.** Proposed driving waveform for new AC PDP structure including reset, address, and sustain period.

was produced, the positive charges were accumulated on the Y electrode and a little negative charge was moved toward the X electrode by the high positive bias voltage, $V_b$. During a sustain period, the sustain pulses with two different voltage polarities were applied, which contribute to reducing the potential difference between the A and Y (or X) electrodes, *i.e.*, the electrodes opposite to the electrode where the trigger discharge was produced.

Figure 4(a) shows expanded driving waveform of pulses for one cycle during a sustain period when applying the positive sustain voltage ($V_s$) and the negative trigger voltage ($-V_{tr}$). The corresponding schematic plasma discharge phenomenon and temporal behavior model of the wall charges inside of the PDP cell from the time (i) to (iv) was also shown in Figure 2(b). As the positive pulses was alternately applied to the X and Y electrode under the condition of the grounded A electrode in the conventional sustain period, the sustain discharge was produced between the X and Y electrodes on the front plate. However, the discharge firing voltage between the front electrodes was higher than that between the front and rear electrodes due to the long distance between the X and Y electrodes as shown in Vt close curve of Figure 2(b). Accordingly, if the same conventional driving waveform was used in the new structure, the plate discharge between the front and A electrodes was only produced instead of the surface discharge between the X and Y electrodes. As mentioned above, as the surface discharge between the X and Y electrodes cannot be produced directly, the surface discharge should be induced by the trigger discharge between the one front and A electrodes and then the application of the positive voltage on the other front electrode. It was expected that the wall charges in a cell were distributed by the previous sustain discharge as shown in Figure 4(b)–(i). That is, it was supposed that the negative charges were on the X electrodes and the A electrode of the opposite side to the Y electrode, whereas the positive charges were on the Y electrodes and the A electrodes of the opposite side to the X electrode. At a time of (ii), the negative trigger voltage ($-V_{tr}$) was applied to the X electrodes for producing trigger discharge using the negative charges on the X electrode and the positive charges on the A electrodes. When the positive sustain voltage ($V_s$) was applied to the opposite Y electrode while the trigger discharge was occurred between the X and A electrodes, the surface discharge was produced as shown in Figure 4(b)–(iii) by the space charges in a cell and the positive wall charge on the Y electrode.

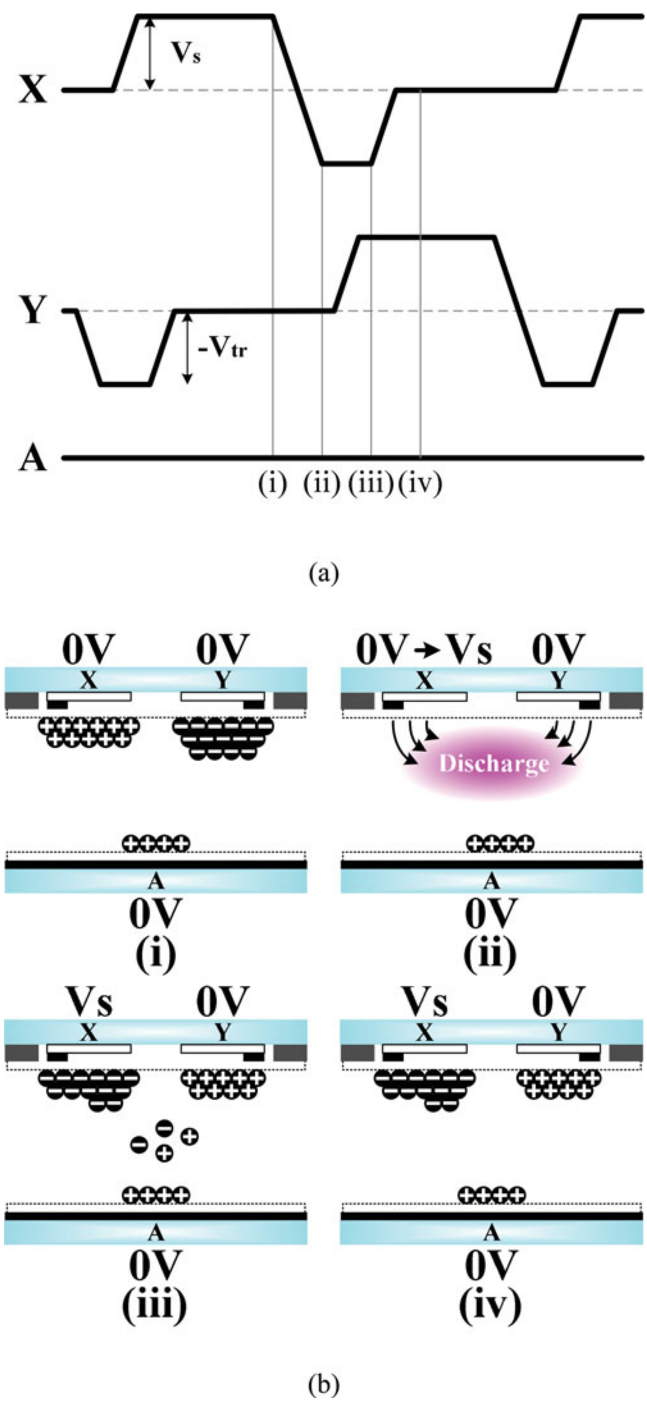



**Figure 4.** (a) Expanded new driving waveform of pulses for one cycle during sustain period and (b) corresponding schematic plasma discharge phenomenon and temporal behavior model of wall charge inside of the PDP cell.

Figure 4(b)–(iv) shows a wall charge accumulated on each electrode after the production of the surface discharge.

## 3. Results and discussion

Figure 5 illustrates the sustain voltage and corresponding light waveform measured by oscilloscope during a sustain period when applying the proposed driving waveform to the new structure. It was found that the stable sustain discharge could be maintained by application of the negative trigger voltage and the positive sustain voltage. However, the discharge could not be measured by separation of the trigger and the sustain discharge because the discharge was produced at the same time. If the plate discharge between the front and rear electrodes was only produced instead of the surface discharge between the X and Y electrode on the front plate, the luminance might be decreased as the discharge was produced under the front electrodes and the sustain discharge would be appeared four times every one cycle due to the production of the plate discharge when applying the positive and negative voltages. In addition, if the discharge was only produced between the front and rear electrodes, the continuous sustain discharge was impossible and would be disappeared. The wall charges would be erased by the unstable sustain discharge due to the difference between the positive sustain and negative trigger voltage.

Figure 6 shows the change in the luminance and luminous efficiency when applying the conventional driving waveform to the conventional structure without the negative pulses, and the new driving waveform to the new structure with positive sustain voltage at the fixed negative trigger voltage of −110 V. For the conventional case with the sustain voltage margin from 190 V to 210 V, the luminance was raised in accordance with the applied voltage but luminous efficiency was seen to be saturated. The reason is that the power consumption was more elevated with increase in the voltage. However, in the new case with the long distance between

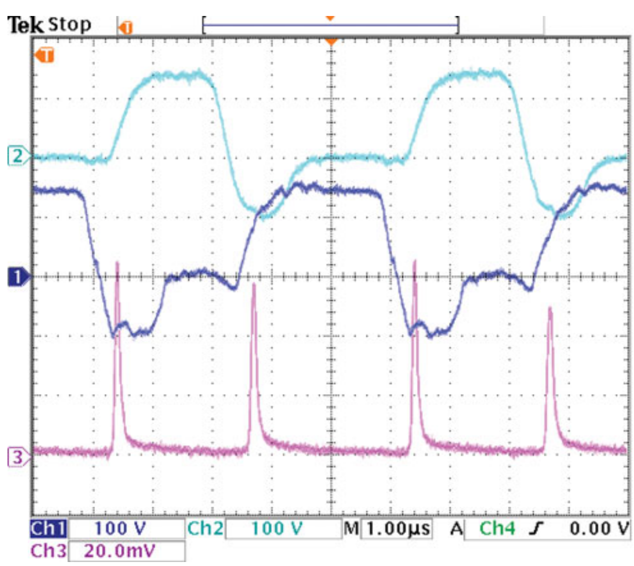



**Figure 5.** Sustain voltage and corresponding light waveforms measured by oscilloscope during sustain period when applying proposed driving waveform to new structure.

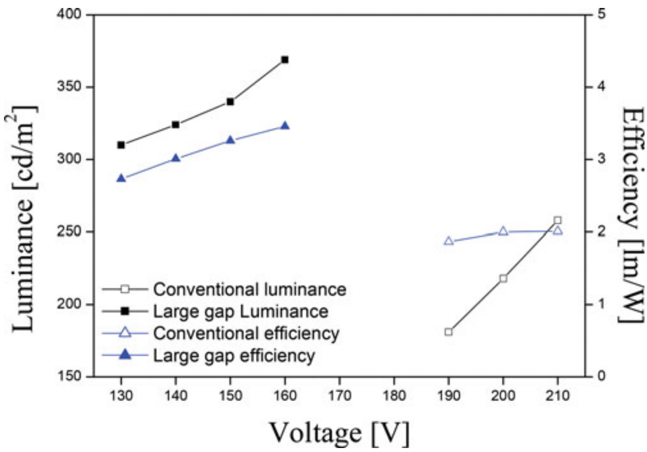



**Figure 6.** Changes in luminance and luminous efficiency when applying conventional driving waveform to conventional structure without negative pulses and new driving waveform to new structure with positive sustain voltage at fixed negative trigger voltage of −110 V.

the X and Y electrodes, as the positive column for the high luminous efficiency in AC PDP was generated, both the luminance and luminous efficiency were increased.

## 4. Conclusions

The luminance and luminous efficiency in the new structure with high Xe gas mixture and long distance between the X and Y electrodes was higher than that in the conventional structure. However, since the surface discharge between the X and Y electrodes in the new structure could not directly produced during a sustain period when applying the conventional driving method, the new driving method was proposed that the negative trigger voltage was first applied before applying the positive sustain voltage. Adopting the proposed driving method to the condition of the new panel with the Xe gas mixture of 15% and the distance between the X and Y electrodes of 500 $\mu$m, the luminance of 340 cd/m$^2$ and luminous efficiency of 3.26 lm/W were obtained in 42 inch AC PDP under the positive sustain voltage of 140 V and the negative trigger voltage of −110 V. That is, the luminous efficiency of the new driving method in the new structure was increased about 63% compared with the conventional case.

## Funding

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