Improvement of Luminous Efficacy Using Short Sustain Pulsewidth and Long Off-Time Between Sustain Pulses in AC Plasma Display Panel

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***Abstract*—This paper investigated the discharge characteristics driven by a short sustain pulsewidth according to the sustain pulsewidth and the off-time between the sustain pulses in an ac plasma display panel. As a result, the luminous efficacy was found to increase when decreasing the sustain pulsewidth due to a reduced ion heating loss. Furthermore, it was shown that the sustain discharge mode could be controlled by adjusting both the sustain pulsewidth and the off-time. It should be noted that the luminous efficacy was significantly improved when the sustain discharge was made to occur outside the sustain pulsewidth due to the minimized ion heating loss. Consequently, under this experimental condition, a sustain pulsewidth of 0.4 μs and an off-time of 10 μs produced the maximum luminous efficacy of 3 lm/W, which was almost double the value obtained with the conventional sustain pulsewidth of 2 μs and the off-time of 10 μs.**

***Index Terms*—Ion heating loss, luminance, luminous efficacy, off-time, plasma display panel (PDP), priming effect, short sustain pulsewidth, wall voltage.**

I. Introduction

PLASMA DISPLAY panels (PDPs) are currently one of the most popular flat displays on the digital TV market due to their excellent image quality, low cost, and fast response time. However, with the rapid progress of liquid crystal display and organic light-emitting diode technology, improving the luminous efficacy of PDPs has become a critical survival issue for the PDP industry. Thus, various approaches, such as the discharge mode, cell structure, gas mixtures, driving waveform, protecting layer, and phosphor material, have already been explored to improve the luminous efficacy [1]–[16].

The luminous efficacy of currently produced PDPs is on the order of 1–2 lm/W, which is very low compared with the 90 lm/W achieved with mercury-free flat fluorescent lamps [17]. When Boeuf analyzed the energy balance in a PDP discharge, he estimated that the ion heating energy loss was around 60% of the electric energy dissipated in a discharge [18]. Therefore, minimizing the ion heating loss would appear to be crucial to improve the luminous efficacy in the discharge process. In general, the ion heating mostly takes place in the sheath region, which is a thin positively charged layer. The formation of the sheath region is mainly attributed to the different mobility of the electrons and ions, and settling the sheath region takes time. Therefore, it has been reported that the luminous efficacy can be improved by decreasing the sustain pulsewidth, as this limits the ion heating loss by preventing the transfer of electrical power to the ions [16], [19], [20]. Originally, the PDP driving scheme used a short (or narrow) pulsewidth to eliminate the wall charges in the reset process. However, this changed with the invention of a self-erasing discharge that uses a high voltage pulse and a weak discharge that uses a ramp reset pulse. In addition, using a short sustain pulse is difficult as it should cooperate with the energy recovery circuit. As a result, the characteristics of a discharge driven by a short sustain pulsewidth have not yet been extensively studied [21].

Therefore, this paper investigated the discharge characteristics according to the short sustain pulsewidth below 1 μs and the off-time between the sustain pulses in an ac PDP. Section II presents the details of the experimental setup, and the discharge characteristics according to the sustain pulsewidth and the off-time are presented in Section III-A–C, respectively. The final conclusions are then summarized in Section IV. Based on the experimental results, it was found that a short sustain pulsewidth with a sufficiently long off-time significantly improved the luminous efficacy due to a reduced ion heating loss.

II. Experimental Setup

The cell structure of the 7-in test panel is that of a conventional reflective three-electrode surface discharge-type ac PDP composed of common electrodes (X), scan electrodes (Y), and address electrodes (A). The detailed specifications of the test panel are listed in Table I. Fig. 1 shows a schematic of the sustain driving waveform used in this paper, where the sustain discharge is ignited by a pair of write pulses (Vw) applied to the X and Y electrodes, respectively, and then repetitively sustained by sustain pulses (Vs) without any energy recovery circuits. In this paper, the A electrodes are floated to prevent discharges between the A and X (or Y) electrodes. The luminance and luminous efficacy were measured for 30 sustain pulse pairs during 1 ms. The sustain pulsewidth included the rising and

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TABLE I
SPECIFICATIONS OF A 7-IN TEST PANEL

Component	Value
Panel size	7 inchies
Working-gas	Ne-Xe(4%), 400torr
Electrode gap	80㎛
Height of Barrier	125㎛
Width of ITO	300㎛

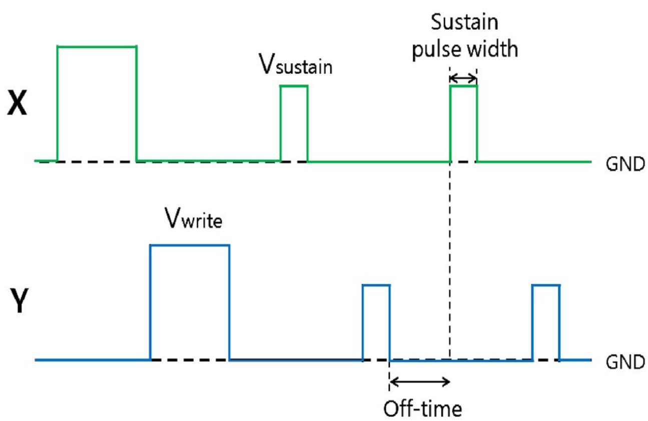

Fig. 1. Schematic of the sustain driving waveform used in this paper.

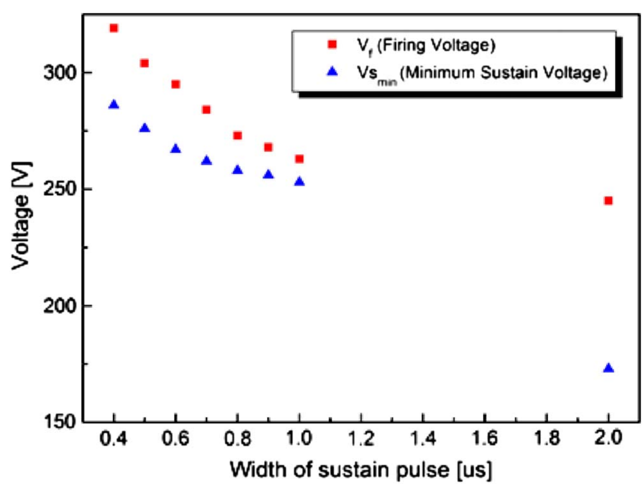

Fig. 2. Firing and minimum sustain voltages as a function of the sustain pulsewidth.

falling time, which were approximately 50 ns, respectively. The off-time was defined as the interval between the sustain pulses.

III. Results and Discussion

A. Discharge Characteristics Relative to Sustain Pulsewidth

The priming effect is a very important factor influencing the discharge characteristics, as presented in Section III-B. Therefore, the measurements were taken when the off-time was 10 μs in order to minimize the priming effects. Fig. 2 shows the firing and minimum sustain voltages as a function of the sustain pulsewidth, where the firing and minimum sustain voltages increased when decreasing the sustain pulsewidth. Note the significant increase in the firing and minimum sustain voltages when the sustain pulsewidth is below 1 μs instead of 2 μs, which is the conventional sustain pulsewidth. This can be explained by the wall voltage relative to the sustain voltage according to the sustain pulsewidth, as shown in Fig. 3. The wall voltages in Fig. 3 were measured at 200 μs after the last sustain pulse [22]. When the sustain pulsewidth was 2 μs, the wall voltage was around 120 V with a sustain voltage of 200 V. In contrast, the wall voltage significantly decreased when the sustain pulsewidth was below 1 μs, as shown in Fig. 3, due to the occurrence of a self-erasing discharge. The low wall voltages are related to the narrow static voltage margin, as shown in Fig. 2. In this experiment, the margins in short pulsewidths are about 20–30 V, as shown in Fig. 2. If we measure the dynamic voltage margin, including the address voltage margin, the operating ranges will be much narrower. This part needs further studies for real application.

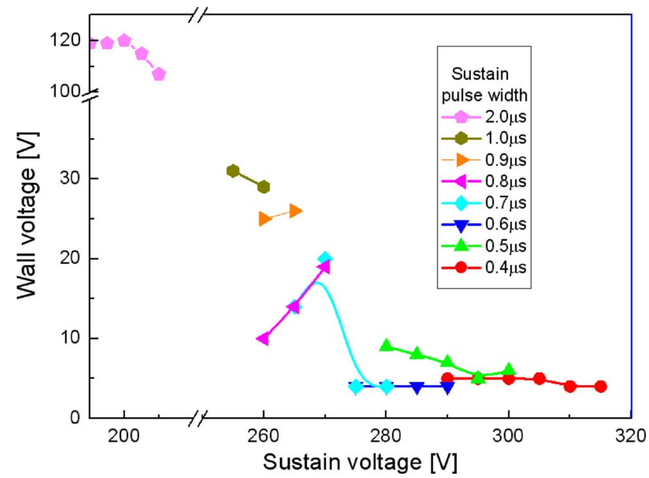

Fig. 3. Wall voltages as a function of sustain voltages at various sustain pulsewidths.

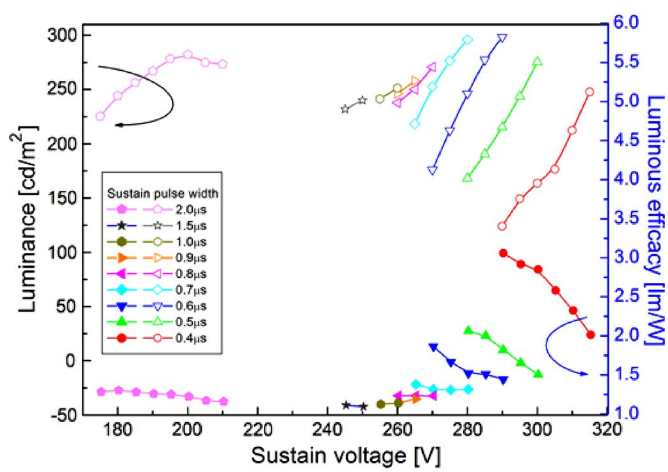

Fig. 4. Luminance and luminous efficacy as a function of the sustain voltage on the dependence of the sustain pulsewidth.

Fig. 4 shows the luminance and luminous efficacy as a function of the sustain voltage according to the sustain pulsewidth. The luminance decreased while the luminous efficacy increased when decreasing the sustain pulsewidth. It should be noted that the luminous efficacy significantly increased when the sustain pulsewidth was 0.4 μs. Fig. 5(a)–(d) show the infrared (IR)

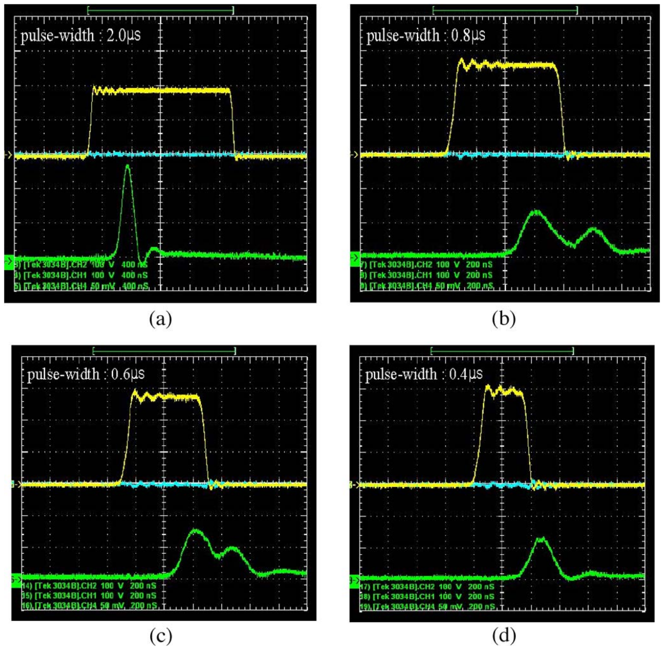

Fig. 5. IR waveform relative to the sustain pulsewidth. (a) Sustain pulsewidth is 2.0 μs, and the sustain voltage is 190 V. (b) Sustain pulsewidth is 0.8 μs, and the sustain voltage is 260 V. (c) Sustain pulsewidth is 0.6 μs, and the sustain voltage is 275 V. (d) Sustain pulsewidth is 0.4 μs, and the sustain voltage is 295 V.

emissions according to the sustain pulsewidth. In Fig. 5(a), the sustain discharge occurred within a sustain pulsewidth of 2 μs, which is the conventional sustain pulsewidth. Meanwhile, in Fig. 5(b) and (c), a self-erasing discharge occurred due to the strong priming effects. However, in Fig. 5(d), the sustain discharge occurred outside the sustain pulsewidth when the sustain pulsewidth was 0.4 μs. Therefore, since most of the ion heating losses take place in the sheath region, as previously described, it can be inferred that the significant improvement in the luminous efficacy was due to a reduced ion heating loss when the sustain pulsewidth was 0.4 μs. In other words, the ion heating loss was reduced when shortening the duration of the sheath formation. In addition, when comparing Fig. 5(d) with Fig. 5(b) and (c), it is important that no self-erasing discharge occurred.

B. Discharge Characteristics Relative to Off-Time

Fig. 6 shows the luminance and luminous efficacy as a function of the sustain voltage according to the off-time when the sustain pulsewidth was 0.4 μs. The operating voltages increased when increasing the off-time due to the weakening of the priming effects. As shown in Fig. 6, the trend of the luminance and luminous efficacy significantly differed according to an off-time above or below 3 μs. When the off-time was below 3 μs, the luminance and luminous efficacy slightly increased when increasing the sustain voltage. However, when the off-time was over 3 μs, the luminance and luminous efficacy significantly increased when increasing the sustain voltage. Therefore, it can be inferred that the discharge mode differed according to an off-time above or below 3 μs.

Fig. 7(a) and (b) shows the IR waveforms according to the off-time, where (a) is when the off-time was 1.5 μs and

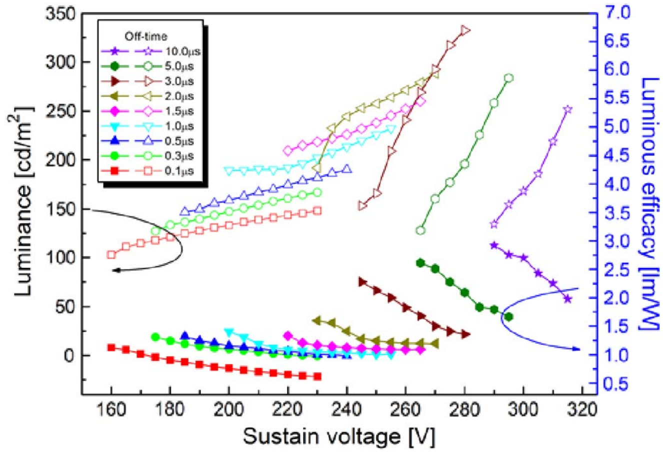

Fig. 6. Luminance and luminous efficacy as a function of the sustain voltage relative to the off-time of sustain pulses when the sustain pulsewidth is 0.4 μs.

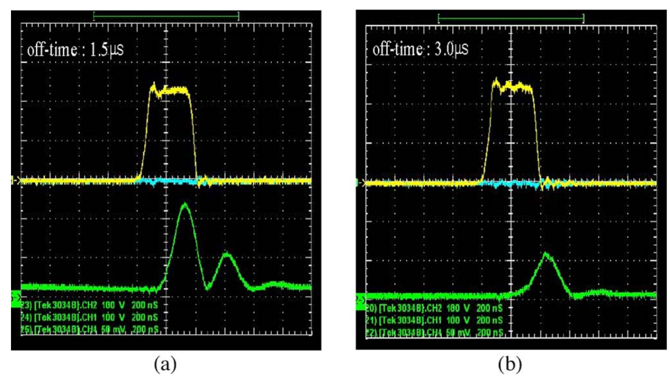

Fig. 7. IR waveform relative to the off-time. (a) Off-time is 1.5 μs, and the sustain voltage is 230 V. (b) Off-time is 3 μs, and the sustain voltage is 245 V.

the sustain voltage was 230 V, and (b) is when the off-time was 3 μs and the sustain voltage was 245 V. As shown in Fig. 7(a), when the off-time was 1.5 μs, the main sustain discharge quickly occurred within the sustain pulsewidth due to the strong priming effects, and a self-erasing discharge then occurred when the sustain voltage returned to the ground voltage. In contrast, as shown in Fig. 7(b), when the off-time was 3 μs, the sustain discharge occurred outside the sustain pulsewidth due to the weakened priming effects, and no self-erasing discharge occurred. Therefore, as previously described, it can be inferred that the significant improvement in the luminous efficacy was due to the reduced ion heating loss when the off-time was over 3 μs.

Thus, based on the experimental results, the luminous efficacy improved when the sustain discharge was generated outside the sustain pulsewidth due to a reduced ion heating loss. However, even when the sustain pulsewidth is sufficiently short, generating the sustain discharge outside the sustain pulsewidth is difficult due to the strong priming effects when the off-time between the sustain pluses is short. Therefore, when applying a short sustain pulsewidth to the conventional sustain driving waveform, minimizing the priming effects is very important in order to generate the sustain discharge outside the sustain pulsewidth. From the experimental results, the luminous efficacy was significantly improved when the off-time between the

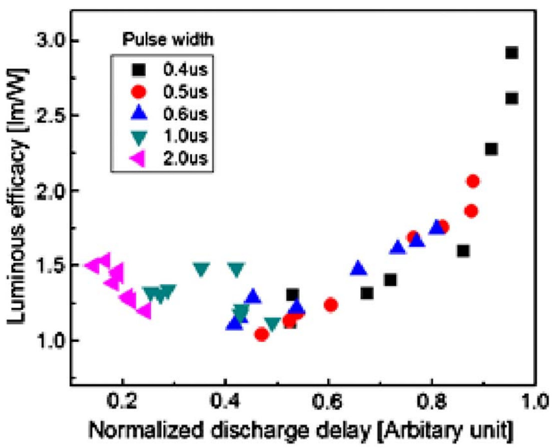

Fig. 8. Relations between NDD and luminous efficacy.

sustain pulses was greater than approximately 3 μs. However, the number of sustain pulses decreased when increasing the off-time, resulting in low luminance. Therefore, a driving waveform needs to be developed that can reduce the off-time.

C. Relations Between Normalized Discharge Delay and Luminous Efficacy

From the previous sections, the luminous efficacy is dependent not only on the sustain pulsewidth but also on the off-time between sustain pulses. The significant improvement in the luminous efficacy is obtained when the sustain discharge is occurred outside the sustain pulsewidth, which can minimize the ion heating loss. Basically, the luminous efficacy increases when decreasing the sustain pulsewidth because the occurrence of sustain discharge is shifted to the outside of the sustain pulsewidth, as shown in Fig. 7(a)–(d). However, even if the sustain pulsewidth is sufficiently short, the sustain discharge cannot be generated outside the sustain pulsewidth when the off-time is short to provide the strong priming effects, as shown in Fig. 7(a) and (b).

Therefore, we can infer that the relative discharge delay time compared to the sustain pulsewidth is more important rather than its absolute value. Thus, we introduced the normalized discharge delay (NDD), which is defined as the discharge delay time divided by the sustain pulsewidth. The discharge delay time was defined as the time from the 10% of a rising sustain voltage to 90% of the IR emission peak.

Fig. 8 shows the relations between NDD and luminous efficacy, which were measured under various sustain pulsewidths and off-time conditions. It should be noted that the luminous efficacy shows a consistent tendency as a function of the NDD, regardless of the sustain pulsewidth and the off-time. When the NDD is below 0.7, the luminous efficacy slightly changes between 1.0 and 1.5 lm/W. It can be affected by self-erasing discharge, sustain voltage, priming conditions, etc. On the contrary, when the NDD is above 0.7, the luminous efficacy significantly increases. It means that a different discharge mode reducing the ion heating loss is involved in this region. In order to obtain high efficacy, consequently, it is necessary to generate a discharge in a high NDD region, which can be accomplished with a short sustain pulsewidth and a delayed discharge.

IV. Conclusion

The influence of the sustain pulsewidth and the off-time between the sustain pulses on the sustain discharge characteristics has been experimentally investigated to improve the luminous efficacy in an ac PDP. As a result, the luminous efficacy was found to increase when decreasing the sustain pulsewidth due to a reduced ion heating loss. In addition, it was shown that the sustain discharge mode could be controlled according to the conditions of the sustain pulsewidth and the off-time between the sustain pulses. It should be noted that the luminous efficacy was significantly improved when the sustain discharge occurred outside the sustain pulsewidth due to the minimized ion heating loss.

However, when the off-time was too short to generate a self-erasing discharge, the sustain discharge quickly occurred within the sustain pulsewidth, which then decreased the luminous efficacy. Thus, for a significant improvement in the luminous efficacy, a sufficiently long off-time is important to weaken the priming effects, thereby allowing the sustain discharge to occur outside the sustain pulsewidth. Consequently, a sustain pulsewidth of 0.4 μs and an off-time of 10 μs produced the maximum luminous efficacy of 3 lm/W, which was almost double the value obtained with a sustain pulsewidth of 2 μs and an off-time of 10 μs.

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