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Improving luminous efficacy using dual sustain pulse waveform associated with short sustain pulse width in AC-plasma display panels

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In the previous work, we reported that the luminous efficacy was significantly improved using the short sustain pulse width with sufficiently long off-time between sustain pulses. In this paper, we have proposed the dual sustain pulse as an alternative of short sustain pulse width when the off-time is short. We demonstrate that the luminous efficacy can be significantly improved by using the new dual sustain waveform, which is attribute to the effects of the dual sustain pulse as well as short sustain pulse width when the off-time is 1μs. The proper adjustment of the 1st sustain discharge can induce the 2nd sustain discharge out of the sustain pulse, resulting in the high luminous efficacy. Comparing to the luminous efficacy of the conventional case, it is improved by approximately 130 % due to the effects of dual sustain pulse as well as short sustain pulse width. [http://dx.doi.org/10.1063/1.4921030]

I. INTRODUCTION

Various studies have been intensively carried out to improve luminous efficacy which is critical survival issue in AC-PDPs.[1–11] Since the discharge characteristics are strongly related to sustain pulse waveforms, the modified sustain pulse waveforms have been proposed to improve the luminous efficiency.[12–15] Nevertheless, it is still necessary to improve the luminous efficacy to survive in the display market.

We previously reported that the luminous efficacy could be improved by using the dual sustain pulse waveform with two rising steps to produce dual sustain discharge per sustain pulse.[16,17] It was confirmed that the longer-sustained discharge owing to the dual sustain discharge could reduce power consumption without sacrificing luminance, thereby improving luminous efficacy. Furthermore, we reported the discharge characteristics driven by a short sustain pulse width waveform.[18] The luminous efficacy was significantly increased, when the sustain discharge was produced out of the sustain pulse in order to minimize the ion heating loss.[19,20] However, it was difficult to generate the sustain discharge out of the sustain pulse due to the high sustain voltage and strong priming effect when the off-time between the sustain pluses was short. Accordingly, the high luminous efficacy could be only obtained under sufficiently long off-time to minimize priming effects in the previous work.

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In general, as the sustain pulse-width decreases, the sustain voltage increases to maintain the sustain discharge because the wall voltage is decreased. However, a high sustain voltage with short pulse width can produce the discharge within the sustain pulse width due to the strong priming effect when the off-time is short. In order to apply the short sustain pulse width to a conventional driving scheme, there might be two approaches to solve it; *i.e.* reducing the high sustain voltage or minimizing the priming effect. In this context, the dual sustain pulse waveform seems to be suitable for compensating the short sustain pulse width. Since the dual sustain discharge is comprised of the 1^{st} and 2^{nd} sustain discharge due to two rising steps of sustain pulse in sequence, the 2^{nd} sustain discharge is considerably influenced by the previous 1^{st} sustain discharge. This implies that properly adjusting the 1^{st} sustain discharge can control the delay and intensity of the 2^{nd} sustain discharge. Therefore, the 2^{nd} sustain discharge can be produced by lower sustain voltage comparing to the high sustain voltage, required for the short sustain pulse width waveform. Furthermore, the delay time of the 2^{nd} sustain discharge for producing out of the sustain pulse can be controlled by adjusting the duration time of the 1^{st} sustain pulse.

In this paper, we have applied the dual sustain pulse as an alternative of short sustain pulse width to a conventional driving scheme. It has been demonstrated that as a result of properly adjusting the 1^{st} sustain pulse, the dual sustain pulse waveform is the effective alternative as the short sustain pulse width. The experimental results confirm that the luminous efficacy can be significantly improved due to the effects of dual sustain pulse as well as short sustain pulse width when the optimized dual sustain pulse is applied to a conventional high frequency driving scheme.

II. EXPERIMENTAL

Figure 1 shows a schematic diagram of the experimental setup employed in this study. The 4-inch test panel has three electrodes where X is the sustain electrode, Y is the scan electrode, A is the address electrode. The gas pressure and gas mixture of the 4-inch test panel are 420 Torr and Ne-He (50 %)-Xe (11 %), respectively. The detailed specifications of the 4-inch test panel are given in Table I. The luminance and power consumption are measured by using a color analyzer (CA-100 Plus) and power meter (WT210), respectively. The IR emissions are measured by using the photo-sensor amplifier (Hamamatsu C6386).

Figures 2(a) and 2(b) show the test driving scheme with a conventional and dual sustain pulse waveform, respectively, used in this study. As shown in Fig. 2(a), the frequency of sustain pulse is 200 kHz and the width of sustain pulse is 1.5 μs. Accordingly, the off-time between sustain pulses is 1 μs. As shown in Fig. 2(b), the dual sustain pulse has two different voltages of V_1 and V_2 and the pulse-width per one sustain pulse is divided into T_1 for V_1 and T_2 for V_2. Accordingly, the dual sustain discharge is comprised of the 1^{st} sustain discharge by V_1 plus 2^{nd} sustain discharge by V_2 in sequence.

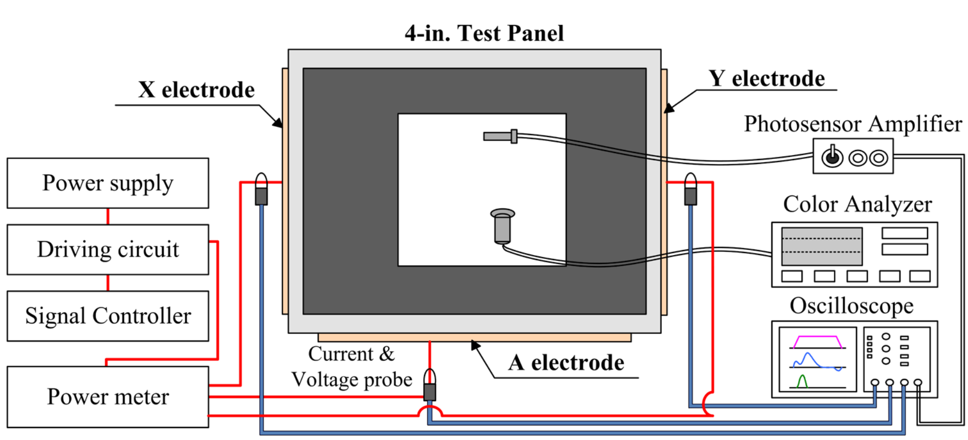

FIG. 1. Schematic diagram of experimental setup employed in this study.

TABLE I. Specifications of 4-in. test panel employed in this study.

Front panel		Rear panel	
ITO width	225 μm	Barrier rib width	55 μm
ITO gap	70 μm	Barrier rib height	110 μm
Bus width	50 μm	Address width	90 μm
Cell pitch		858×808 μm	
Barrier rib type		Closed rib	
Gas Pressure		420Torr	
Gas chemistry		Ne-He (50 %)-Xe (11 %)	

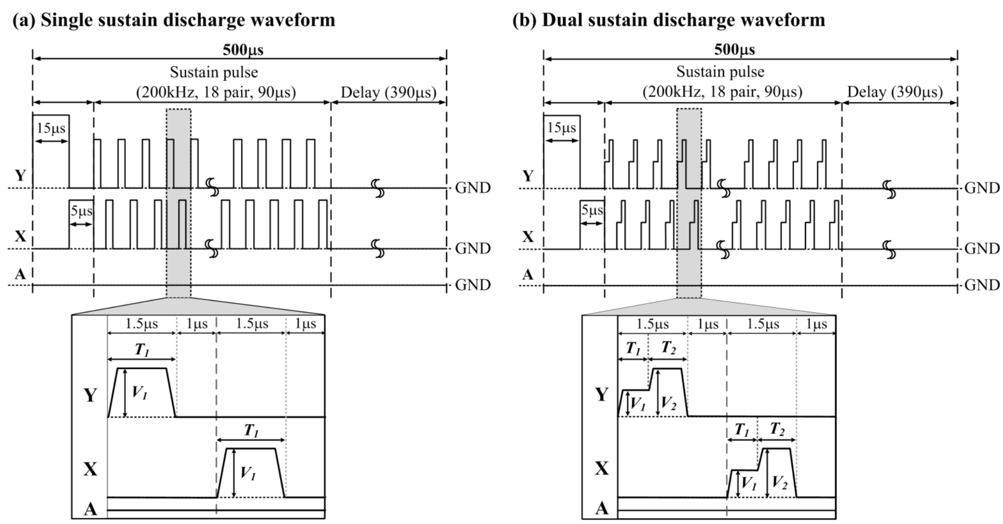

FIG. 2. Driving waveforms of (a) single and (b) dual sustain discharge waveforms for investigating discharge characteristics related to pulse width variation.

III. RESULTS AND DISCUSSION

The dual sustain pulse waveform has four parameters, *i.e.* T_1, T_2, V_1, and V_2. We have attempted to investigate the correlation between the parameters, however, it has been very difficult to find out due to the complicate correlation between them. Figures 3(a), 3(b), and 3(c) show the IR emission waveforms relative to T_1, when V_1 is 135 V, 150 V, and 165 V, respectively. The total sustain pulse width ($=T_1 + T_2$) is fixed at 1.5 μs and V_2 is 250 V. As shown in Fig. 3(a), the 1st discharge is not produced due to the low voltage of V_1 (= 135V). On the contrary, as shown in Fig. 3(c), the 2nd discharge is not produced because the voltage difference between V_2 and V_1 is too low to produce the 2nd discharge. Both the 1st and 2nd sustain discharge are stably produced as V_1 of around 150 V under this condition. In particular, it should be noted that in order to obtain the effect of short sustain pulse width by using the dual sustain pulse, the intensity of 2nd sustain discharge should be stronger than that of 1st sustain discharge. Accordingly, the preliminary experimental conditions are determined based on the results of Fig. 3. However, the range of V_1 to produce stable dual sustain discharges vary depending on varying T_1 and T_2.

Figure 4 shows the delay time of 1st and 2nd sustain discharge measured from Fig. 3(b). The 1st delay time is slightly increased while 2nd delay time is increased corresponding to increment of T_1. Though it seems to be intuitive result, it should be noted that it demonstrates the possibility of dual sustain pulse, *i.e.* instead of short sustain pulse-width, to improve luminous efficacy when the off-time is short. In the previous work, it was difficult to produce the sustain discharge out of the sustain pulse width due to the combination of the high sustain voltage and strong priming effect when the off-time was short. However, as shown in Fig. 3(b), note that the off-time is 1 μs, the 2nd delay time is mainly controlled by T_1 due to the complicated effects related to the priming effect and

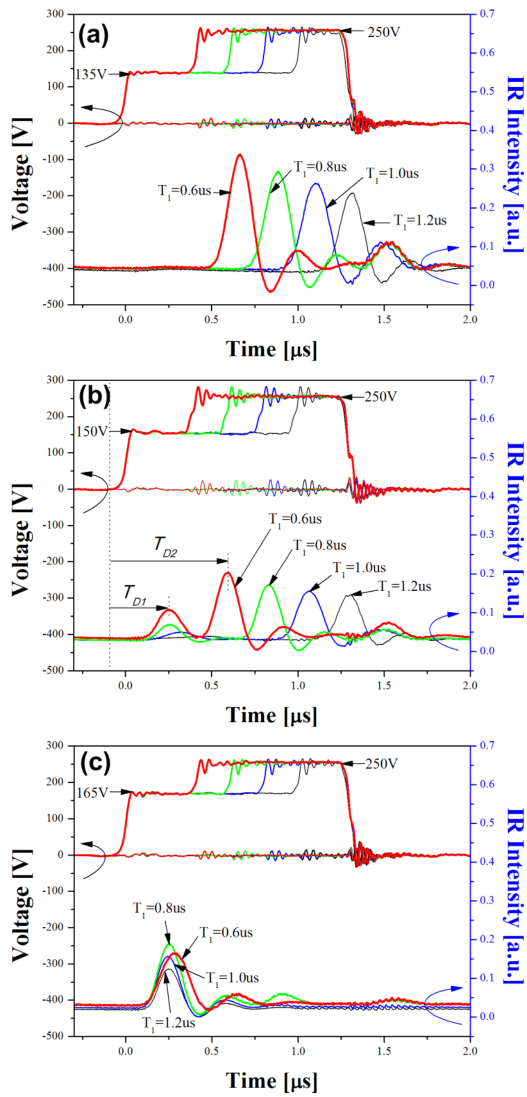

FIG. 3. Changes in IR emission waveforms relative to various pulse width of T_1, when V_1 is (a) 135 V, (b) 150 V, and (c) 165 V.

wall voltage. As T_1 increases, the 2nd delay time is mainly determined by the cell voltage (= wall voltage + applied voltage) and the priming effect due to the 1st sustain discharge.

Figure 5 shows the relation between the luminous efficacy and the integrated IR emission ratio of the 2nd sustain discharge to 1st sustain discharge calculated from the IR intensity curve of Fig. 3(b). As shown in Fig. 3(b), though the intensity of 2nd sustain discharge is decreased as increases T_1, the intensity of 1st sustain discharge is much decreased. Accordingly, the IR ratio is increased as increases T_1. As shown in Fig. 5, we can clearly see the correlation between the luminous efficacy and IR emission ratio. As shown in Fig. 3(b), the 2nd sustain discharge is produced and delayed corresponding to increasing of T_1. Note that when the T_1 is 1.2 μs, the 2nd sustain discharge is generated near the falling edge of sustain pulse, which is much similar to the IR emission waveform obtained to improve the luminous efficacy in the previous work.[18] Consequently, we can confirm that the dual sustain pulse waveform can be an alternative waveform as a short sustain pulse waveform when the off-time is short.

In order to investigate the effect of T_2 on the luminous efficacy, several experimental conditions are selected for case study, as shown in Table. II. Figures 6(a), 6(b), and 6(c) show comparison

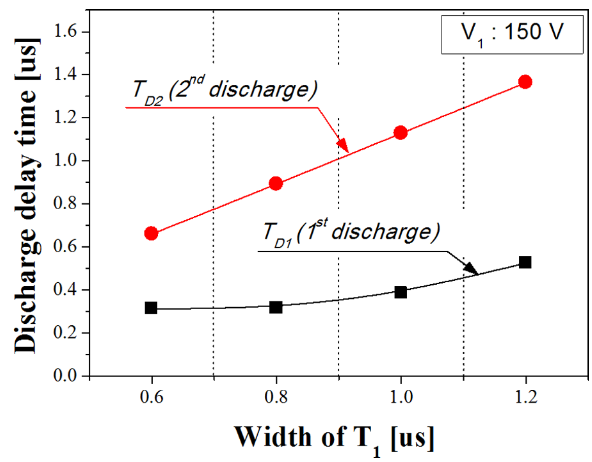

FIG. 4. Changes in discharge delay times of 1st and 2nd discharge relative to various width of T_1 under Fig 3(b) condition.

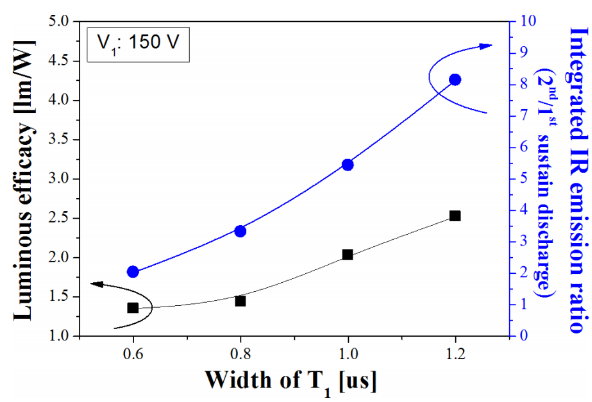

FIG. 5. Relation between luminous efficiency and integrated IR emission ratio of the 2nd sustain discharge to 1st sustain discharge calculated from IR intensity curve of Fig 3(b).

TABLE II. Various pulse width and applied voltage conditions on dual sustain discharge waveform employed for case study.

Case	T_1 [μs]	T_2 [μs]	V_1 [V]	V_2 [V]
Conventional	1.5		180~220V	
I (i)	0.6	0.9	125	220~235
I (ii)	0.6	0.6	150	235~250
I (iii)	0.6	0.3	175	260~270
II (i)	0.8	0.7	135	230~240
II (ii)	0.8	0.5	150	235~245
II (iii)	0.8	0.3	165	260~270
III (i)	1.0	0.5	150	245~255
III (ii)	1.0	0.3	160	265~275
IV	1.2	0.3	160	265~275

of the luminance, discharge power, and luminous efficacy relative to T_2, respectively. As shown in Fig. 6(a), for all cases, the range of luminance and incremental tendency relative to V_2 are similar, except for operation voltage of V_2. On the contrary, the discharge power and luminous efficacy show the remarkable difference in value, as shown in Figs. 6(b) and 6(c). Therefore, we can easily judge that the luminous efficacy is improved due to the reduction of discharge power, attributed effects related to the dual sustain discharge pulse as well as short sustain pulse width.

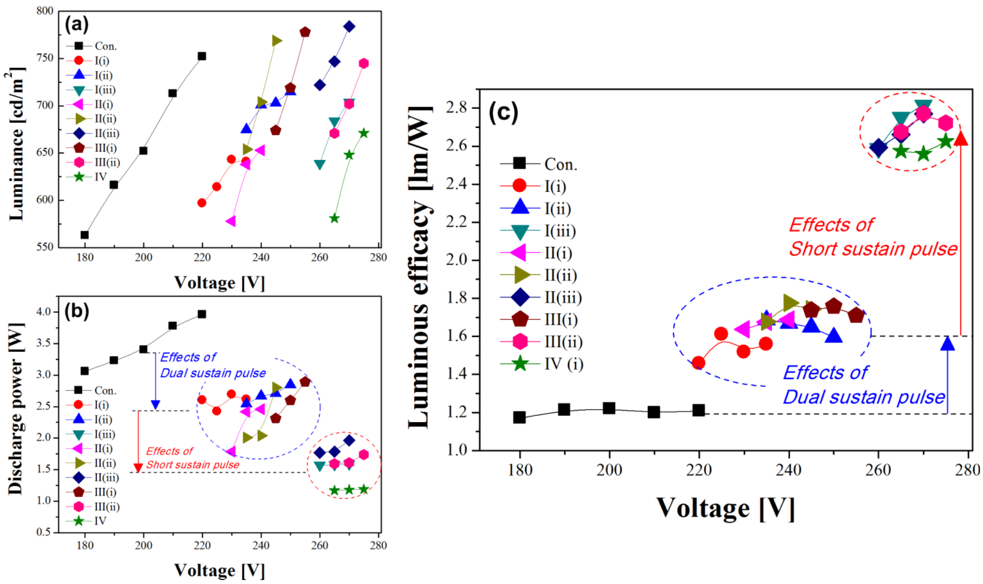

FIG. 6. Comparison of (a) luminance, (b) discharge power, and (c) luminous efficacy of dual sustain pulse waveform relative to T_2.

The division of note is shown in Figs. 6(b) and 6(c). The data except for the conventional case can be divided into two groups. The first and second groups include data ranging from 220 to 255 V and from 260 to 280 V, marked in figures, respectively. It can be clearly inferred that the improvement of luminous efficacy is mainly related to the effects of dual sustain pulse and short sustain pulse width. Note that all cases of second group have a 0.3 μs of T_2, as shown in Table. II. Figures 7(a) and 7(b) show the typical IR waveforms of the case I (i) and II (iii) which are selected from first and second group, respectively. The interval between the 1st and 2nd sustain discharge of the case II (iii) is longer than that of the case I (i), even V_2 (= 270 V) in Fig. 7(b) is higher than V_2 (= 235 V) in Fig. 7(a). However, the duration time T_1 and voltage V_1 of the 1st sustain pulse in Fig. 7(b) are longer and higher than those of the 1st sustain pulse in Fig. 7(a), respectively. For the case II (iii) of Fig. 7(b), the more amounts of wall charges with opposite polarity are accumulated on the electrodes due to the longer T_1 and higher V_1, thereby resulting in weakening the electric field intensity within the cell. Thus, the 2nd sustain discharge is delayed, as shown in the case II (iii) of Fig. 7(b).

Therefore, we can clearly infer that 1st sustain discharge plays important role in producing 2nd sustain discharge out of the sustain pulse width, meaning that the 2nd sustain discharge can be produced out of the sustain pulse width when off-time is as short as 1μs by properly adjusting the duration time T_1 and voltage V_1 of the 1st sustain pulse. Furthermore, it should be also emphasized

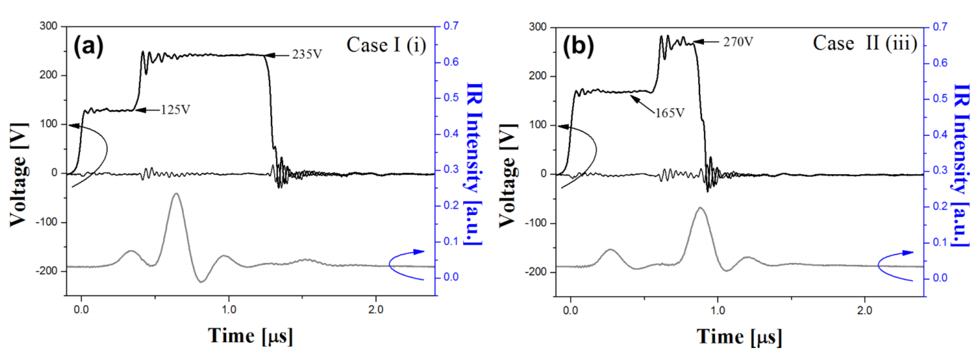

FIG. 7. Typical IR waveforms selected from first and second groups: (a) Case I(i) and (b) Case II(iii).

that the improvement of the luminous efficacy for the proposed dual sustain pulse waveform associated with short sustain pulse width strongly depend on the production of the 2^{nd} sustain discharge out of the sustain pulse width.

IV. CONCLUSIONS

In the previous work, we confirmed that the luminous efficacy was significantly improved by applying the short sustain pulse width with sufficiently long off-time between sustain pulses which could not directly apply to a conventional high frequency driving waveform. In this study, we demonstrate that the luminous efficacy can be significantly improved by applying the dual sustain pulse waveform as an alternative of short sustain pulse width when the off-time is short. When the off-time is 1 μs, the 2^{nd} sustain discharge can be produced out of the sustain pulse using the dual sustain pulse waveform, resulting in the high luminous efficacy. Comparing to the luminous efficacy of the conventional case, it is improved by approximately 130 % due to the effects of dual sustain pulse as well as short sustain pulse width.

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