Improvement of Color Temperature Using Independent Control of Red, Green, Blue Luminance in AC Plasma Display Panel

Ki-Duck Cho, *Member, IEEE*, Heung-Sik Tae, *Member, IEEE*, and Sung-Il Chien, *Member, IEEE*

***Abstract*—This paper presents a new driving scheme for the improvement and flexibility of a color temperature without sacrificing a peak white luminance using an independent control of the red (R), green (G), and blue (B) luminance in an alternate current plasma display panel (ac-PDP). The independent control for the R, G, and B emissions can be achieved by selective application of the various narrow auxiliary pulses to the R, G, and B address electrodes during a sustain-period. The auxiliary pulses can control the luminance levels independently from the R, G, and B cells by forming the fast and efficient plasma or by slight disturbing of the wall charge accumulation. By the application of various auxiliary pulses leading to the simultaneous control of each color's luminance, it is observed that the new driving scheme can improve the color temperature from 5396 K to 10 980 K in a 4-in test panel with almost the same peak white luminance as that of the conventional driving scheme.**

***Index Terms*—Auxiliary address pulse, color temperature, plasma display panel.**

I. Introduction

PLASMA display panels (PDPs) are considered to be most suitable for the large area full color wall hanging flat panel display devices. Lately, in the commercial display market, PDPs are also considered as a promising candidate for the large area digital high definition televisions (HDTVs). From a viewpoint of an image quality, however, PDPs must overcome several serious problems for the complete replacement of the conventional cathode ray tube (CRT). The essential issues in image quality of the PDP are the low color temperature [1], the low contrast ratio [2], the dynamic false contour [3]. In particular, the color temperature of the PDP is still quite low when compared with that of the CRT. The low color temperature of the PDP is inherently attributed to the lower blue luminance than the red or green luminance. Several new methods have been suggested to improve the color temperature of the PDP. Some suggested methods are as follows: an asymmetric barrier rib [4], a color filter [5], and a new protection layer [6]. Nevertheless, these methods cannot solve the low color temperature problem fundamentally. Another conventional problem about the color temperature of the PDP is that the color temperature cannot be varied arbitrarily depending on the preference of the customers once the cell structure and the related driving scheme are fixed. The white color in the PDP is realized by a superposition of the R, G, and B lights emitted from the R, G, and B cells. In general, the white color in a display device such as the PDP can be characterized by the color temperature, or more specifically, the correlated color temperature, which is defined as the temperature of the blackbody radiator whose perceived color most closely resembles that of the given radiator [7]. The low color temperature in the current ac-PDP is fundamentally attributed to the lower blue luminance than the red or green luminance. The physical spectrum intensity in the blue region of 380 nm to 500 nm are quite stronger than those in the green region of 500 nm to 580 nm and the red region of 580 nm to 780 nm, whereas the perceiving efficiency of the human eyes is very low in the blue region. Accordingly, the blue luminance needs to be increased considerably so as to improve the color temperature of the ac-PDP.

In this paper, a new driving scheme using an auxiliary pulse is suggested to improve the color temperature and acquire flexibility of the color temperature in an ac-PDP. The luminance levels of the R, G, and B lights can control arbitrarily by selective applying of the various auxiliary pulses to the R, G, and B cells during a sustain-period. The variations of the luminance levels for the R, G, and B cells are also examined under the various auxiliary pulsing conditions such as changes in the amplitude, width, and delay time of a pulse.

II. Experimental Setup

Fig. 1 shows the experimental setup for the optical and electrical measurements of the 4-in test panel in the case of adopting the new driving scheme. The specification of the test panel employed in the current study is listed in Table I. The cell structure employed in this research is the conventional coplanar-type with three electrodes X, Y, and Z [8]. A single pixel of the PDP is composed of the R, G, and B cells, whose discharge volumes are separated by the symmetric striped barrier ribs. Each cell has three electrodes, i.e., sustain electrodes X and Y, address electrode Z, where the sustain electrodes X and Y lie perpendicular to the address electrode Z. The driving conditions for sustain pulses are a voltage of 180 V, a frequency of 100 kHz, and a duty ratio of 40%. The voltage waveforms generated from the driving circuits are controlled by the logic pulses from the logic signal generator. The voltage pulses powered by several power supplies are finally applied to three electrodes of the test panel to produce the plasma. The visible emission spectra from

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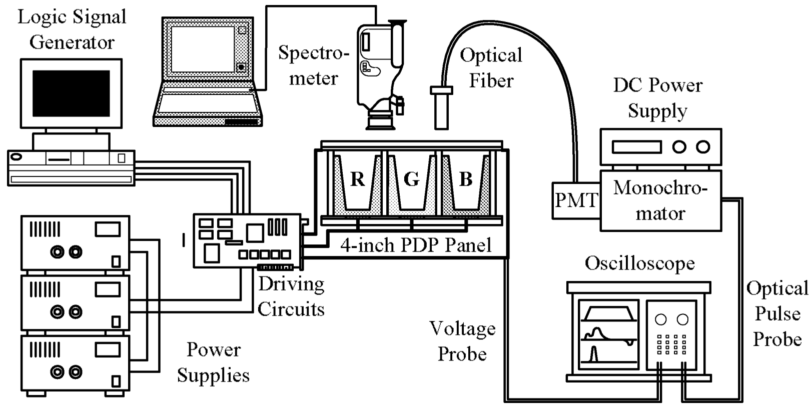


Fig. 1. Experimental setup for optical and electrical measurement of 4-in test panel employed in this research.

TABLE I
SPECIFICATION OF 4-IN TEST PANEL

Front Panel		Rear Panel	
ITO Width	310 μm	Address Electrode Width	100 μm
ITO Gap	80 μm	Barrier Rib Width	70 μm
Bus Electrode Width	100 μm	Barrier Rib Height	130 μm
Dielectric Thickness	30 μm	Rib Pitch	360 μm
MgO Thickness	5000 Å		
Gas Composition: He-Ne(7:3)-Xe(4%)		Gas Pressure: 400 Torr	

the PDP cells are measured by the PR-704 spectrometer. The infrared (IR: 828 nm) waveforms from the PDP cells are also measured by photo multiplier tube (PMT) converting the measured infrared signals into the electrical signals. The color temperature and CIE chromaticity coordinates are obtained from the measured visible emission spectrum data of the test panel using the PR-704 spectrometer.

III. RESULTS AND DISCUSSION

A. New Driving Scheme Using Auxiliary Short Pulses

Fig. 2(a) shows the driving waveforms applied to the 4-in test panel for the reset-, address-, and sustain-periods. Since the waveforms, particularly for the reset- and address-periods employed in this new driving scheme are typically used in the conventional address-display-separated (ADS) driving scheme, the corresponding reset and address discharge characteristics are observed to be almost the same as those in the conventional ADS driving method (not shown here) [9]. As shown in Fig. 2(a), in a conventional driving scheme, no auxiliary pulse is applied to the address electrode Z during a sustain-period, when the sustain pulses are alternately applied to the sustain electrodes X and Y. Consequently, the address electrodes are not utilized to produce a plasma during a sustain-period. Thus, the luminance from the R, G, and B cells of the PDP is controlled only by the sustain pulses. Since the sustain pulses are commonly connected to the R, G, and B cells, the luminance levels of the R, G, and B colors are difficult to control separately in the current driving technique of the PDP with three electrodes. However, the address electrodes parallel with the symmetric striped barrier ribs

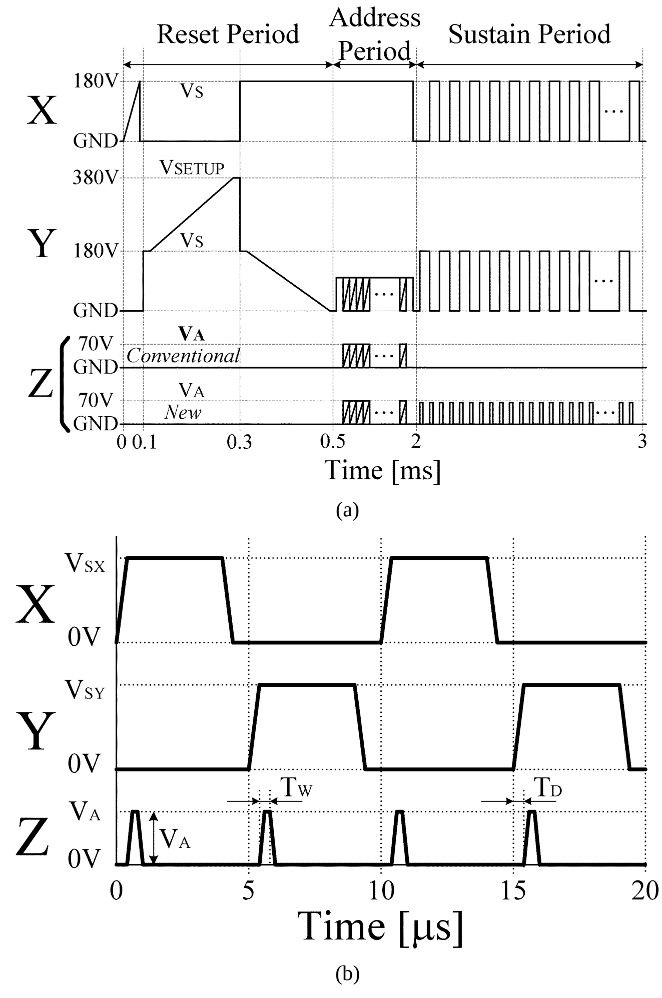


Fig. 2. Driving waveforms (a) of 4-in test panel and voltage waveforms (b) applied to three electrodes X, Y, and Z for luminance control during sustain-period.

are located individually in each R, G, and B cell. If the address electrodes are used to take part in the discharge by proper applying of the different auxiliary pulses to the address electrodes during a sustain-period, the luminance levels among the R, G, and B cells can be controlled independently. It was reported in [8] that the proper control of the amplitudes and widths of the auxiliary address pulse during a sustain-period can improve both the luminance and the luminous efficiency in the PDP. In order

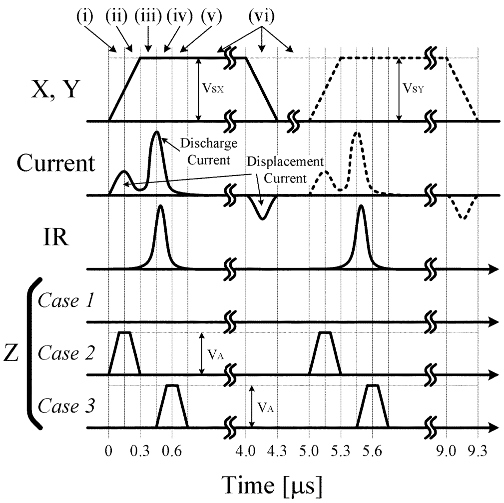


Fig. 3. Displacement current, discharge current, and infrared (828 nm) waveforms when two sustain pulses are applied to sustain electrodes and no auxiliary is applied to address electrode (Case 1: conventional driving method). Two different types of new auxiliary pulses applied to address electrodes during sustain-period (Cases 2 and 3: new driving method).

to improve and control the color temperature, the blue luminance should increase remarkably, whereas the red luminance should decrease slightly with independent control of each color luminance. Hence, first of all, the luminance variation should be investigated according to the application conditions of the auxiliary pulses based on the discharge characteristics in the R, G, and B cells. In this work, as for the auxiliary pulses, the three parameters such as amplitude V_A, width T_W, and delay time T_D from a rising edge of the sustain pulse, are chosen to investigate the influence on the variation of the discharge characteristics, as shown in Fig. 2(b). When the sustain pulses V_{SX} is applied to the sustain electrode X and no auxiliary pulse is applied to the address electrode, as shown in Case 1 of Fig. 3, the displacement current flows for about 0.3 μs through the dielectric layer prior to the flow of the discharge current. Thereafter, if the electric field intensity induced by the sustain voltage satisfies the discharge ignition condition, the discharge current begins to flow, implying that a plasma is produced within the cell. The IR of 828 nm is also emitted from the cell while the discharge current is flowing from 0.3 μs to 0.6 μs, as shown in (iii, iv) of Fig. 3. During this time, the space charges such as electrons and ions, generated from the plasma, are attracted toward the sustain electrodes in an opposite direction to the electric field induced by the external sustain voltage V_{SX}. The conversion process from the space charges into the wall charges during a discharge continues until the total electric field is too weak to maintain the discharge due to the opposite electric field induced by the accumulated wall charges.

Based on the experimental result for the discharge current flowing from 0.3 μs to 0.6 μs in the case of the conventional driving method (Case 1), the two different types of auxiliary pulses are chosen to be applied to the address electrode, as shown in Cases 2 and 3 of Fig. 3. The auxiliary short pulse in Case 2 is applied to the address electrode prior to the flow of the discharge current. It is expected that this additional short pulse prior to the main discharge can assist in producing the faster and more efficient plasma for the improvement of the luminance.

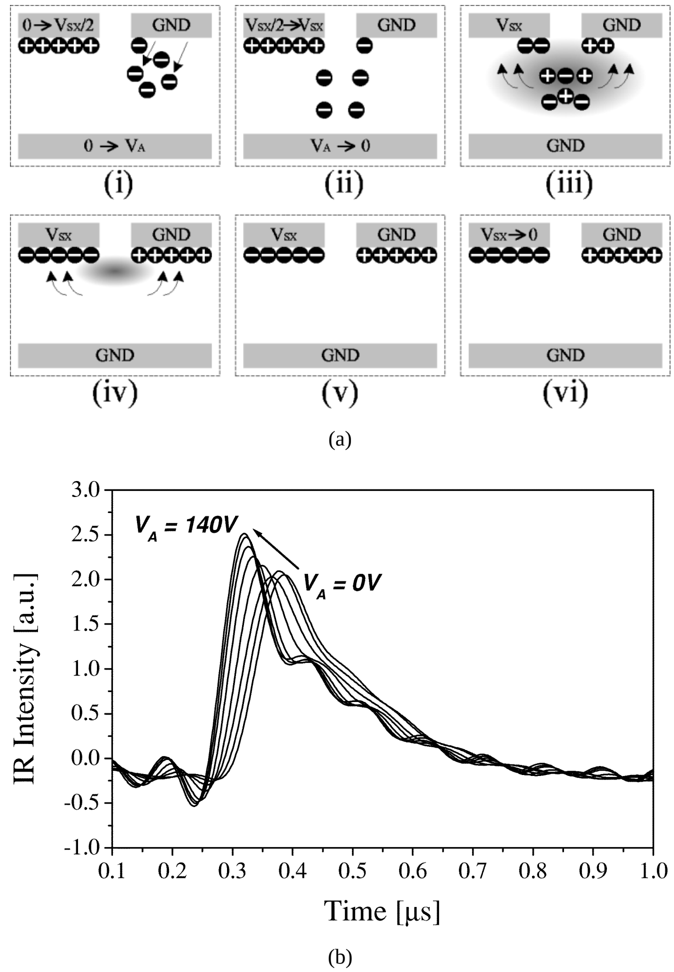
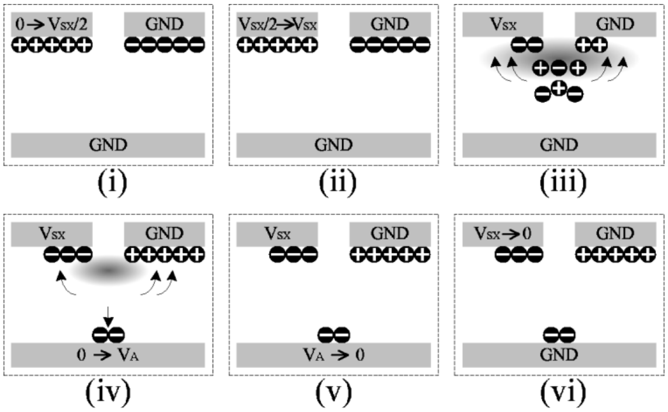


Fig. 4. Schematic model (a) of space charges/wall charges within PDP cell and measured IR (828 nm) waveforms (b) in case of adopting auxiliary pulse shown in Case 2 of Fig. 3.

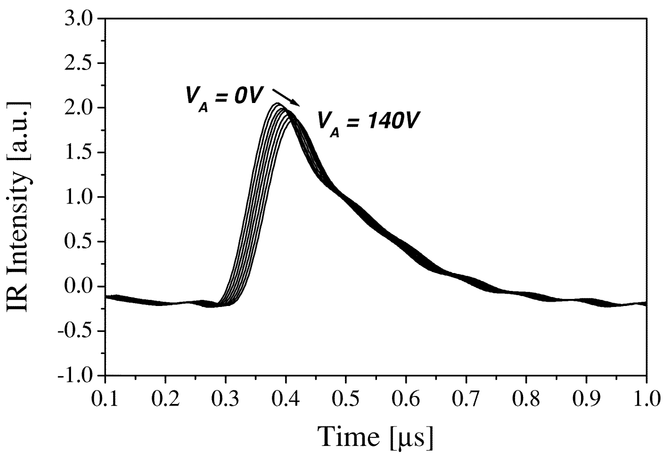
Another case (Case 3) is that the auxiliary short pulse is applied to the address electrode with some delay time of about 0.45 μs. It appears that this additional short pulse would reduce the luminance slightly by disturbing the wall charge accumulation on the sustain electrodes. However, in Case 3, careful attention should be paid to the proper choice of the delay time for the slight disturbance of the wall charge accumulation.

B. Independent Control of Luminance Levels for Red, Green, and Blue Cells Using New Driving Scheme

Fig. 4(a) shows the schematic model of the space charges/wall charges within the PDP cell when the auxiliary pulse shown in Case 2 of Fig. 3 is applied simultaneously to the address electrode. The pulsewidth of the auxiliary pulse is fixed as 200 ns, whereas the amplitudes of the auxiliary pulse vary from 0 V to 140 V. The driving condition for the sustain pulses are the same as that in Case 1 of Fig 3. The rising rate (rising time: 100 ns) of the auxiliary short pulse V_A is higher than that (rising time: 300 ns) of the sustain pulse V_{SX}. This positive auxiliary short pulse with a high rising rate attracts the electrons accumulated on the sustain electrode Y toward the address electrode Z, as shown in (i) of Fig. 4(a). The electrons detached by the auxiliary short pulse can work as the priming particles at the initiation of the discharge by the sustain pulse. Accordingly, this transition



(a)



(b)

Fig. 5. Schematic model (a) of space charges/wall charges within PDP cell and measured IR (828 nm) waveforms (b) in case of adopting auxiliary pulse shown in Case 3 of Fig. 3.

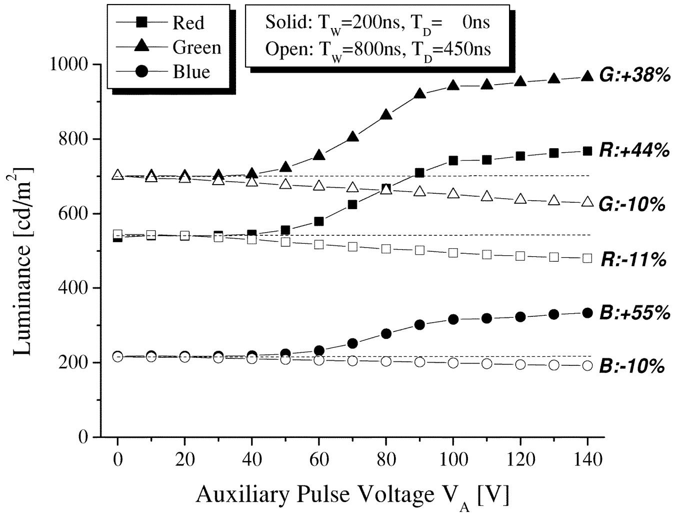


Fig. 6. Changes in R, G, and B luminance levels of 4-in test panel by applying two different types of auxiliary pulses: luminance-enhancing auxiliary pulse (solid mark) and luminance-lessening auxiliary pulse (open mark).

of these electrons from wall charges into space charges prior to an ignition of the sustain discharge can promote the activation of the plasma discharge, as shown in (ii, iii) of Fig. 4(a). These priming particles, i.e., electrons in this case, can play a role not only in improving the discharge efficiency but also in forming the faster discharge because they can produce the plasma efficiently even under the weak electric field condition. As illustrated in the measure IR (828 nm) waveforms of Fig. 4(b), the peaks of the IR waveforms are observed to be shifted to the left and to get higher with an increase in the amplitude of the auxiliary pulse from 0 V to 140 V, confirming that the plasma is produced fast and efficiently under the weak electric field condition. It is also observed that as the pulsewidth is wider than 200 ns, the contribution to the fast and efficient plasma generation is reduced gradually (not shown here). This effect is thought to be presumably due to the disturbance of the wall charge accumulation during the sustaining discharge caused by the auxiliary pulse with the pulsewidth wider than 200 ns.

Fig. 5(a) illustrates the schematic model of the space charges/wall charges within the PDP cell when the auxiliary pulse shown in Case 3 of Fig. 3 is applied simultaneously to the address electrode. The application time of the auxiliary pulse is delayed for about 450 ns from the rising edge of the sustain pulse. The pulse width of the auxiliary pulse is fixed as 200 ns, whereas the amplitudes of the auxiliary pulse vary from 0 V to 140 V. The driving condition for the sustain pulses are the same as that in Case 1 of Fig. 3. When a plasma is produced within a cell by applying the sustain pulse, the wall charges begins to be accumulated below the sustain electrodes, as shown in (iii) of Fig. 5(a). Most of wall charges are accumulated from 0.3 μs to 0.6 μs, as indicated in the IR data of Fig. 5(b). If the auxiliary pulse is applied at about 0.45 μs to an address electrode, this positive pulse would attract the space charges such as the electrons toward the address electrode, thus resulting in disturbing the accumulations of the wall charges toward the sustain electrodes, as shown in (iv) of Fig. 5(a). Accordingly, some electrons are accumulated on the address electrode, even though the other electrons are accumulated on the sustain electrode, as shown in (v) of Fig. 5(a). The wall charges on the address electrode scarcely participate in the next sustain discharge because the application of the auxiliary pulse is delayed for 0.45 μs. This also means that the wall charges on the address electrodes hardly contribute to producing the sustain discharge because the subsequent discharge is ignited only between the sustain electrodes X and Y by applying the sustain pulse to the sustain electrode. Therefore, the luminance decreases in inverse proportion to the increase in the amount of wall charges accumulated on the address electrode.

Unlike the IR waveform of Fig. 4(b), the peaks of the IR (828 nm) waveforms of Fig. 5(b) are observed to be slightly shifted to the right and to get lower as the amplitude of the auxiliary pulse increases from 0 V to 140 V, confirming that the delayed auxiliary pulse disturbs the accumulation of the wall charge toward the sustain electrodes. It is also observed that as the pulsewidth is wider than 200 ns, the IR peak is reduced to a greater extent and shifted farther to the right (not shown here). This phenomenon is presumably due to the fact that more wall charges tend to be accumulated on the address electrode rather than on the sustain electrode in proportion as the pulse width of the auxiliary pulse gets wider than 200 ns.

Fig. 6 illustrates the changes in the R, G, and B luminance levels of the 4-in test panel in the case of adopting the two dif-

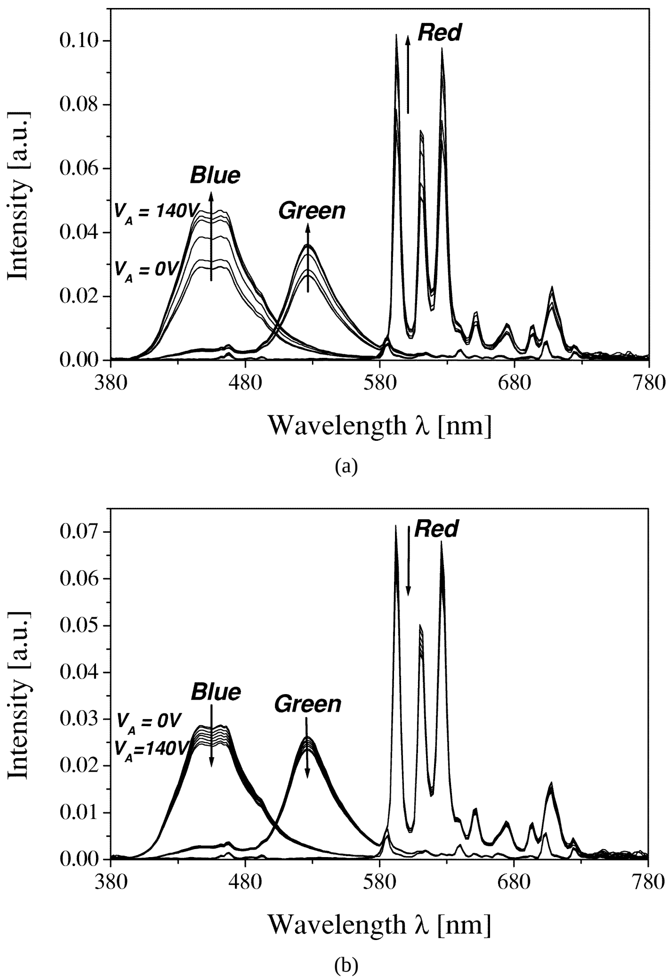


Fig. 7. Visible spectra from R, G, and B cells of 4-in test panel when luminance-enhancing auxiliary pulse (a) and luminance-lessening auxiliary pulse (b) are applied to address electrodes, respectively.

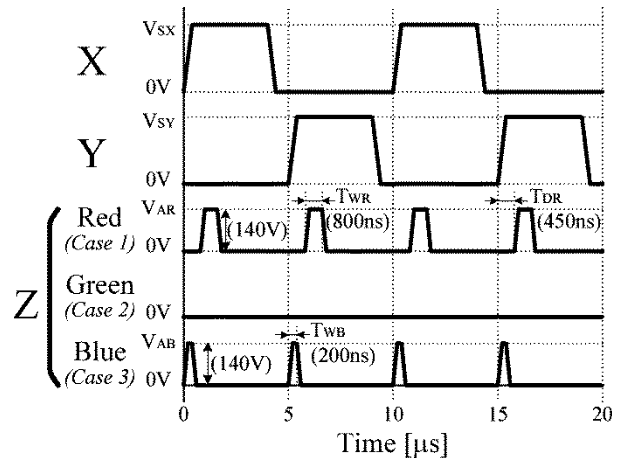


Fig. 8. Timing diagram of sustain voltage waveforms, V_{SX} and V_{SY}, and three different types of auxiliary pulses V_{AR}, V_{AG} (=0), and V_{AB}, where V_{SX} and V_{SY} are applied to sustain electrodes and V_{AR}, V_{AG} (=0), and V_{AB} are simultaneously applied to address electrodes of R, G, and B cells, respectively for maximally improving color temperature.

ferent types of auxiliary pulses, i.e., the luminance-enhancing pulse and the luminance-lessening pulse. All the auxiliary short pulses applied at the same starting time as the two sustain pulses can also act as the luminance-enhancing pulses, which can increase the luminance levels of the R, G, and B lights (not shown here). In particular, the maximum enhancement of the R, G, and B luminance levels is obtained at the pulse width of 200 ns, as shown in the solid marks of Fig. 6. As shown in the maximum luminance enhancing pulse condition of Fig. 6, the increase rates in the luminance levels for the R, G, and B lights are 44% (from 535 cd/m^2 to 768 cd/m^2) for a red color, 38% (from 701 cd/m^2 to 967 cd/m^2) for a green color, and 55% (from 217 cd/m^2 to 336 cd/m^2) for a blue color, each being compared to the luminance level with no auxiliary pulse. On the other hand, all the auxiliary short pulses with delay times up to 600 ns relative to the two sustain pulses can also reduce the luminance levels of the R, G, and B lights (not shown here). It is observed that the application of the auxiliary short pulse with a width of 800 ns and a delay time of 450 ns achieves the maximum reduction of the luminance levels of the R, G, and B lights, as shown in the open marks of Fig. 6. As shown in the minimum luminance-lessening pulse condition of Fig. 6, the decrease rates in the luminance levels for the R, G, and B lights are 11% (from 535 cd/m^2 to 487 cd/m^2) for a red color, 10% (from 701 cd/m^2 to 632 cd/m^2) for a green color, and 10% (from 217 cd/m^2 to 195 cd/m^2) for a blue color, each being compared to the luminance level with no auxiliary pulse. The visible spectra emitted from the R, G, and B cells of the 4-in test panel are also measured when the luminance-enhancing pulses and luminance-lessening pulses are applied to the address electrodes, respectively, as illustrated in Fig. 7. Under the luminance-enhancing pulse conditions of Fig. 7(a), the R, G, and B spectra are increased. Similarly, under the luminance-lessening pulse conditions of Fig. 7(b), the R, G, and B spectra are decreased.

C. Improvement of Color Temperature Using Independent Control of Luminance Levels for Red, Green, and Blue Cells

Fig. 8 shows the timing diagram of the voltage waveforms in the new driving scheme to improve the color temperature based on the experimental result of B in Section III. For the independent control of the luminance levels for the R, G, and B colors, three different types of auxiliary pulses are applied to the address electrodes of the R, G, and B cells, respectively. Since the high color temperature in the PDP can be obtained by increasing the blue luminance and simultaneously by decreasing the red luminance, the blue luminance-enhancing pulses, i.e., the auxiliary pulses with V_{AB} (140 V), T_{WB} (200 ns), and T_{DB} (0 ns) are applied to the blue cells so as to increase the blue luminance, whereas the red luminance-lessening pulses, *i.e.*, the auxiliary pulses with V_{AR} (140 V), T_{WR} (800 ns), and T_{DR} (450 ns) are applied to the red cells so as to decrease the red luminance, as illustrated in Fig. 8. As for the green cells, no auxiliary pulses are used like the conventional driving method. No misfiring problems are observed in this driving condition.

Fig. 9(a) illustrates the visible spectra of the white color emitted from the R, G, and B cells in the case of adopting the new driving scheme of Fig. 8 relative to the conventional driving scheme. The new driving scheme increases the intensity of blue light in the range of 400 nm to 500 nm considerably, but decreases the intensity of red light in the range of 580 nm to

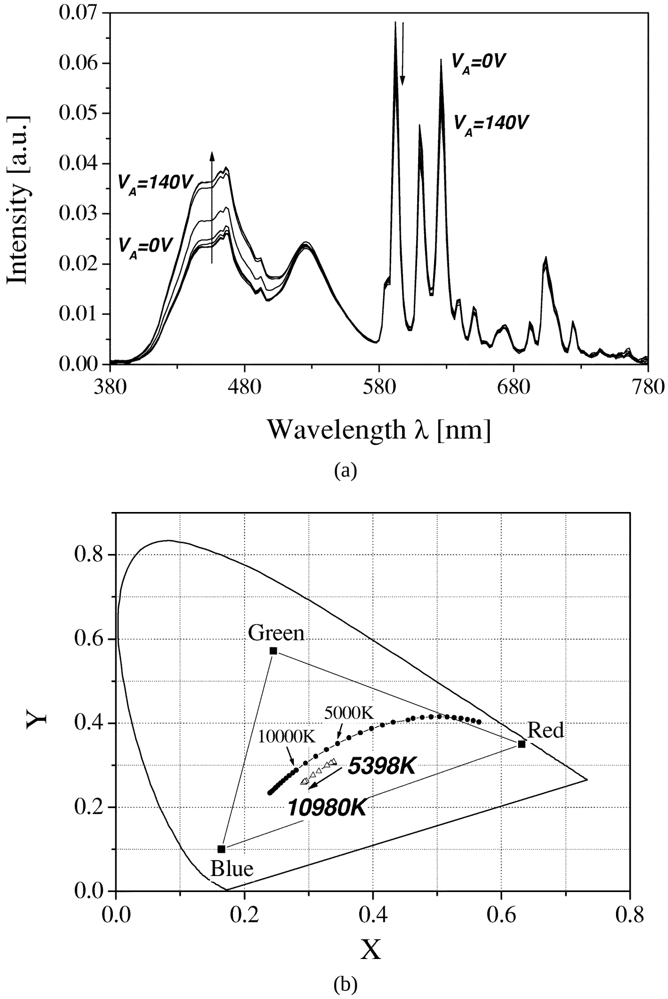


Fig. 9. Visible spectra (a) of white color emitted from R, G, and B cells in case of adopting new driving scheme relative to conventional driving scheme, Changes of color temperature (b) related to black body locus on CIE (1931) chromaticity coordinates measured from 4-in test panel in case of adopting new driving scheme relative to conventional driving scheme.

640 nm slightly. There is no significant change in other regions. Fig. 9(b) illustrates the changes in the color temperature related to the black body locus on the CIE (1931) (x, y)-chromaticity coordinate measured from the 4-in test panel in the case of employing the new driving scheme relative to the conventional driving scheme. The solid square marks denote the National Television System Committee (NTSC) standard coordinates, and the linked solid circles denote the black body locus with the related color temperatures. As a result of adopting the new driving scheme of Fig. 8, the color temperature is increased from 5398 K to 10 980 K without reducing the luminance, as denoted in the open triangle mark in the CIE chromaticity coordinates of Fig. 9(b). This transition of the coordinates of the color temperature toward the blue region from (0.3395, 0.3059) to (0.2940, 0.2614) has resulted from the increment of 55% in the blue luminance and the simultaneous decrement of 11% in the red luminance. Table II shows the CIE chromaticity coordinates and their correlated color temperatures in various auxiliary pulse conditions. The color temperature of the PDP can be controlled in wide range by using the new driving scheme with various auxiliary pulse conditions, as shown in Table II.

TABLE II
COLOR TEMPERATURE VARIATIONS USING NEW DRIVING SCHEME IN 4-IN TEST PANEL

Red		Green		Blue		V_A [V]	CIE 1931		Color Temperature [K]
T_{WR}	T_{DR}	T_{WG}	T_{DG}	T_{WB}	T_{DB}		x	y	
800 nsec Width	450 nsec Delay	No Auxiliary Pulse		200 nsec Width	No Delay	0	0.3390	0.3048	5398
						10	0.3395	0.3059	5378
						20	0.3392	0.3059	5391
						30	0.3391	0.3064	5401
						40	0.3392	0.3074	5399
						50	0.3388	0.3084	5421
						60	0.3347	0.3051	5637
						70	0.3285	0.2994	6001
						80	0.3160	0.2861	6916
						90	0.3069	0.2763	8027
						100	0.2964	0.2630	10529
						110	0.2943	0.2603	10425
						120	0.2929	0.2588	10772
						130	0.2921	0.2584	10930
						140	0.2918	0.2582	10980

IV. CONCLUSION

A new driving scheme for the improvement and flexibility of the color temperature in an ac-PDP without decreasing the gain of the G and R signals or without employing asymmetric cell structures is proposed by using an independent control of the R, G, and B luminance. The luminance levels for the R, G, and B colors can be controlled independently by selective application of the three different types of auxiliary pulses to the R, G, and B cells. It is found that the new driving scheme can improve the color temperature from 5396 K to 10 980 K maximally by independent control of the R, G, and B luminance of a 4-in test panel with almost the same peak white luminance.

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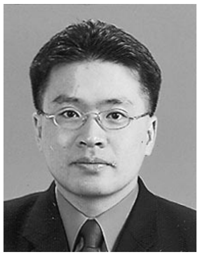

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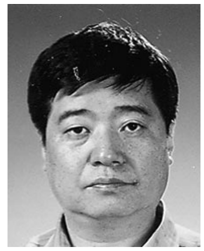

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