Driving Waveform for Reducing Temporal Dark Image Sticking in AC Plasma Display Panel Based on Perceived Luminance

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***Abstract*—Minimizing the reset discharge produced under an MgO-cathode condition and eliminating the wall charges accumulated on the address electrode prior to the reset period are the key factors involved in reducing temporal dark image sticking. Thus, based on the perceived luminance, new driving waveforms that can prohibit an MgO-cathode induced reset discharge or erase the wall charges accumulated on the address electrode prior to the reset period are examined for the complete elimination of temporal dark image sticking without deteriorating the address discharge characteristics. As a result of monitoring the difference in the infrared emission and perceived luminance between the cells with and without image sticking, the proposed driving waveform was shown to effectively remove temporal dark image sticking without deteriorating the address discharge characteristics.**

***Index Terms*—Perceived luminance, prereset waveform, reset discharge under an MgO-cathode condition, temporal dark image sticking.**

I. Introduction

DESPITE the suitability of flat panel devices for digital high definition television, plasma display panels (PDPs) still suffer from the critical problem of image sticking, where a residual image appears in a subsequent image when the previous image has been continuously displayed over a few minutes. When the appearance time of the ghost image is relatively short, such temporal image sticking is also referred to as image retention. Although an iterant strong sustain discharge during a sustain period is known to induce the problem of image sticking, the image sticking phenomenon itself is still not fully understood [1]–[4]. Nonetheless, for dark image sticking, the difference in the breakdown voltage during the ramp-up period between the cells with and without image sticking is known to induce a dark ghost image [1]. As such, this experimental observation indicates that the temporal dark image sticking phenomenon is related to the reset discharge, which is comprised of the surface (X–Y) discharge produced under an MgO-cathode condition, plus the plate gap (A–Y) discharge produced under a phosphor-cathode condition. Furthermore, for the surface reset discharge under an MgO-cathode condition, the MgO surface itself has a more significant effect on the firing condition of the reset discharge, whereas for the plate gap reset discharge under a phosphor-cathode condition, the initial wall charges that accumulate on the address electrode have a more significant effect on the firing condition of the reset discharge. Consequently, the efficient prohibition of a reset discharge under an MgO-cathode condition and the elimination of the wall charges accumulated on the address electrodes prior to the reset period would be expected to be effective in minimizing the difference in the firing voltage between the cells with and without image sticking during the ramp-up period. Furthermore, since the temporal dark image sticking phenomenon is perceived by human eyes, the effect of the nonlinearity of the perception sensitiveness of human eyes, especially under a low background luminance, should be also considered when examining the temporal dark image sticking phenomenon in relation to the application of various driving waveforms [5], [6].

Accordingly, this paper proposes a new driving waveform that can minimize the MgO effect in the reset discharge during the ramp-up period and erase the wall charges accumulated on the address electrode prior to the reset period without deteriorating the address discharge characteristics. The effects of both conventional and the proposed driving waveform on temporal dark image sticking are examined based on the perceived luminance, defined as the luminance perceived by human eyes.

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II. Analysis of Temporal Dark Image Sticking in AC-Plasma Display Panel

A. *Conventional Driving Waveform for Monitoring Temporal Dark Image Sticking*

Fig. 1(a) shows the three electrodes, X, Y, and A, in the 4-in test panel used to monitor the temporal dark image sticking, where the square-shaped pattern (region A) is the discharge region and region B is the nondischarge region. To display only region A on the test panel for 15 min, the driving waveforms shown in Fig. 1(b) were applied repeatedly to the three electrodes, X, Y, and A, in the test panel, where V_x was applied to the common electrode, X, V_{y1} and V_{y2} were applied to the scan electrodes Y_1, and Y_2, respectively, and V_{A1} and V_{A2} were applied to the address electrodes, A_1 and A_2, respectively. Sixty-three sustain pulses were alternately to applied the X and Y electrodes during a sustain period. To produce a residual image caused by image sticking, the entire region of the test panel was then abruptly changed to a dark background image after the

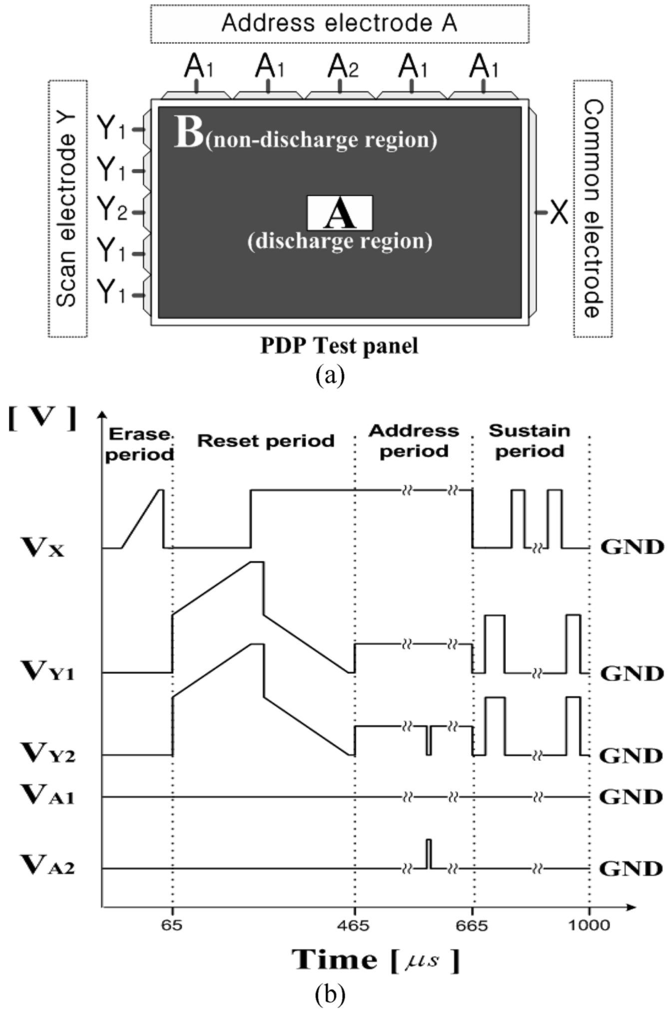


Fig. 1. (a) Three electrodes X, Y, and A in 4-in test panel and (b) driving waveforms used to monitor temporal dark image sticking.

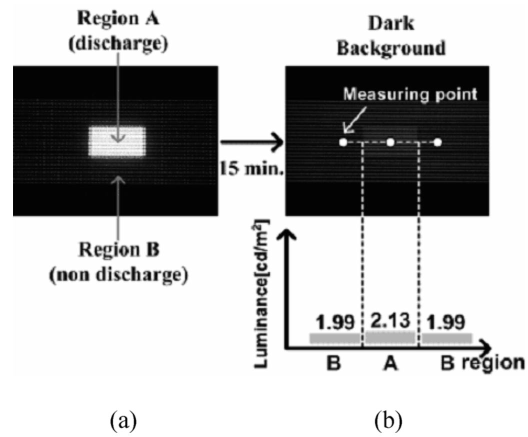


Fig. 2. (a) Original image pattern and (b) residual (or ghost) square-shaped pattern when displaying dark background captured from 4-in test panel.

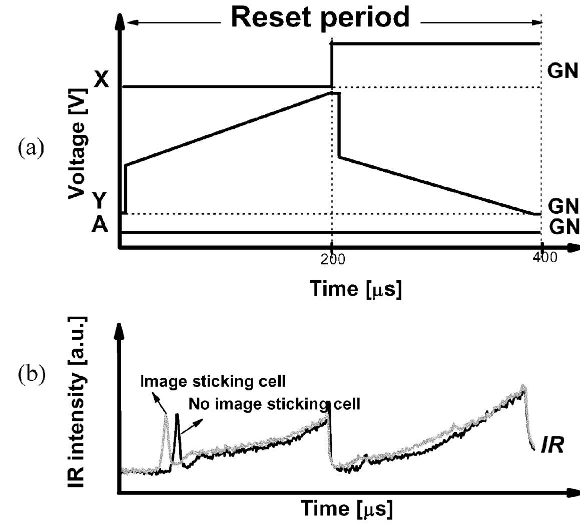


Fig. 3. (b) Changes in IR (828 nm) emissions measured from cells with and without image sticking when (a) applying conventional ramp-reset waveform in Fig. 1(b).

15-min sustain discharge. In this case, no address pulses were applied to the address electrodes, A_1 and A_2. The infrared (IR) emission during the ramp-up period and background luminance were measured and compared as regards the cells with image sticking (region A) and without image sticking (region B) using a luminance analyzer (Chroma meter CS-200) and photosensor amplifier.

B. Temporal Dark Image Sticking Phenomenon and Its Measurement

Fig. 2(b) shows the retention of the square-shaped image pattern under the ensuing dark background image immediately after (a) a 15-min sustain discharge. Since the dark ghost image only lasts for a certain time, the phenomenon is called "temporal dark image sticking." As shown in Fig. 2(b), the ghost image, i.e., square-shaped image pattern, appeared due to the difference in the background luminance $[\Delta L = L_2(2.13) - L_1(1.99) = 0.14\ \text{cd/m}^2]$ between the cells with and without image sticking when displaying the dark background image, indicating that temporal dark image sticking is closely related to the reset discharge during the reset period [1]. As shown in Fig. 2(b), the temporal dark image sticking was monitored in terms of the luminance difference between the cells with and without image sticking when displaying the dark background image. However, when dealing with dark image sticking, the luminance perceived by human eyes should be considered instead of the measured display luminance, as the final estimation for dark image sticking is made by human eyes. Interestingly, human eyes have a nonlinear characteristic in perception sensitiveness, which means that human eyes are very sensitive, especially under a low background luminance [5], [6]. The relation between the display luminance and perceived luminance will be discussed in detail later. Fig. 3 shows the changes in the IR (828 nm) emissions measured from the cells with and without image sticking when applying the conventional ramp-type reset waveform shown in Fig. 1(b) during a reset period. As shown in Fig. 3(b), the IR emission from the image sticking cells was observed to shift to the left, indicating a reduced firing voltage in the image sticking cells. Thus, since a reduction in the firing voltage for the reset discharge during a ramp-up period may be responsible for inducing temporal dark image sticking, the

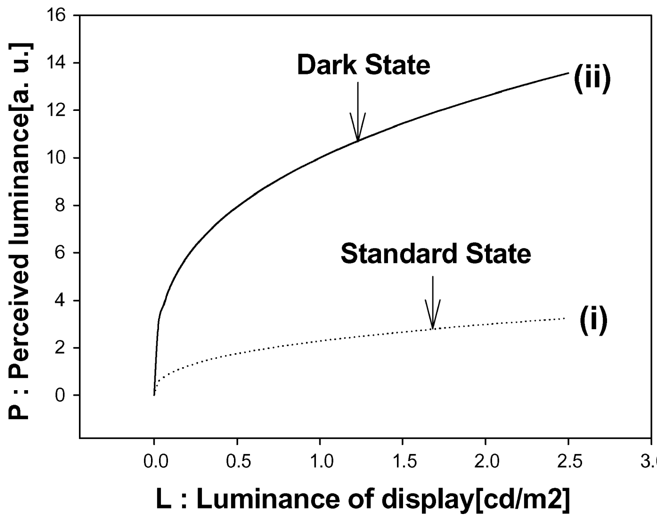


Fig. 4. Correlation between display luminance and perceived luminance [6].

factors affecting the reset discharge during a ramp-up period need to be investigated in detail. Until now, the reduced firing voltage in the image sticking cells has mainly been attributed to the MgO activated surface [1]. The reset discharge during a ramp-up period is comprised of two discharges: an X–Y discharge produced under an MgO-cathode condition, and a Y–A discharge produced under a phosphor-cathode condition. As a result, the reset discharge produced under an MgO-cathode condition needs to be minimized to alleviate the decrease in the firing voltage for the image sticking cells, along with the proper elimination of the wall charges accumulated on the address electrodes prior to the ramp-up period, which can affect the Y–A discharge during the ramp-up period. In this context, various driving waveforms are examined and their functions investigated carefully.

C. Temporal Dark Image Sticking Phenomenon Based on Luminance Perceived by Human Eyes

Fig. 4 shows the correlation between the display luminance and the perceived luminance for two cases, dark and standard states, where the perceived luminance means the luminance perceived by human eyes [6]. The dark state is defined as a state that the surrounding condition is completely dark, so that its light intensity is 0 dB [6]. The standard state is also defined as a state that the surrounding condition is bright, so that its light intensity is between 80 and 90 dB [6]. As shown in Fig. 4, the value of the luminance perceived by human eyes varied relative to the display luminance depending on the surrounding lightness condition, a (i) standard or (ii) dark state, revealing that the values of the perceived luminance can differ even with the same display luminance. In particular, for the dark state, even a small change in the display luminance induced the big difference in the perceived luminance under a low display luminance condition, as shown by (ii) in Fig. 4. The relation between the perceived luminance, P and the display luminance, $L[\mathrm{cd/m^2}]$ is as follows [5], [6]:

$$P = \begin{cases} 2.29\, L^{0.382} & \text{for standard state} \\ 10\, L^{0.333} & \text{for dark state} \end{cases} \quad (1)$$

The display luminance difference, $\Delta L[= L_2(2.13\ \mathrm{cd/m^2}) - L_1(1.99\ \mathrm{cd/m^2})]$ between the cells with and without image sticking shown in Fig. 2(b) was 0.14 $\mathrm{cd/m^2}$. Here, the values of the display luminance for both the cells with and without image sticking were measured using a luminance analyzer (CS-200). Meanwhile, the values of the perceived luminance for both types of cell were calculated from (1) using the data for the display luminance measured using the luminance analyzer (CS-200). For the standard case, at the measured display luminance, $L_1 = 1.99\ \mathrm{cd/m^2}$, the perceived luminance, P_1 was 2.9785 from (1), whereas at the measured display luminance, $L_2 = 2.13\ \mathrm{cd/m^2}$, the perceived luminance, P_2 was 3.0568 from (1). Consequently, the perceived luminance difference, $\Delta P_s(= P_2 - P_1)$ for the standard state was 0.0783. In contrast, for the dark case, at the measured display luminance, $L_1 = 1.99\ \mathrm{cd/m^2}$, the perceived luminance, P_1 was 12.5753 from (1), whereas at the measured display luminance, $L_2 = 2.13\ \mathrm{cd/m^2}$, the perceived luminance, P_2 was 12.8632 from (1). Consequently, the perceived luminance difference, $\Delta P_d(= P_2 - P_1)$ for the dark state was 0.2879. When displaying the dark background image, P_1 was the perceived luminance for the cells with no image sticking, while P_2 was the perceived luminance for the cells with image sticking. Since the final estimation for temporal dark image sticking is made by human eyes, the perceived luminance difference should be considered instead of the display luminance difference when measuring the degree of the induced dark image sticking, i.e., the luminance difference between the cells with and without image sticking.

III. Driving Waveform for Reducing Temporal Dark Image Sticking

A. Two Critical Factors for Temporal Dark Image Sticking

1) Minimization of Reset Discharge Produced Under MgO-Cathode Condition: Fig. 5(a) shows the ramp waveform that can produce a plate gap reset discharge between the Y and A electrodes instead of a X–Y reset discharge between the X and Y electrodes (hereinafter, plate gap reset discharge waveform), where the ramp waveform applied to the Y electrode is similar to that in the conventional ramp waveform, yet another ramp waveform with the same voltage slope of 1.22 $\mathrm{V}/\mu\mathrm{s}$ as that applied to the Y electrode is applied to the X electrode. As such, this other ramp waveform applied to the X electrode plays a role in minimizing the reset discharge between the activated MgO surfaces due to an iterant strong sustain discharge [2]. As shown by the IR emission data in Fig. 5(b), the IR emission was very low for both types of cell (i.e., cells with and without image sticking), because the reset discharge was predominantly produced between the Y and A electrodes. However, the IR emission for the cells with image sticking shifted slightly to the left, meaning that the firing voltage was still somewhat reduced in spite of prohibiting the X–Y discharge during the ramp-up period. Even though the measured display luminance difference, ΔL was considerably reduced to 0.04 $\mathrm{cd/m^2}$ ($\Delta L = 0.14\ \mathrm{cd/m^2}$ for the conventional case), the perceived luminance differences, ΔP_s and $\Delta \mathrm{P}_d$ obtained from (1) were slightly reduced to 0.0669 and 0.2684, respectively ($\Delta P_s = 0.0783$ and $\Delta P_d = 0.2879$ for the conventional case). This

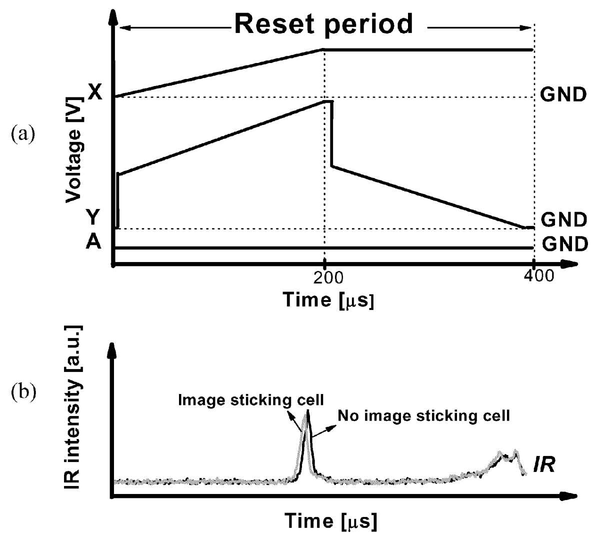


Fig. 5. (a) Plate gap reset discharge waveform for prohibiting X–Y discharge under MgO-cathode condition (case 1), and (b) changes in IR (828 nm) emissions measured from cells with and without image sticking when applying plate gap reset discharge waveform.

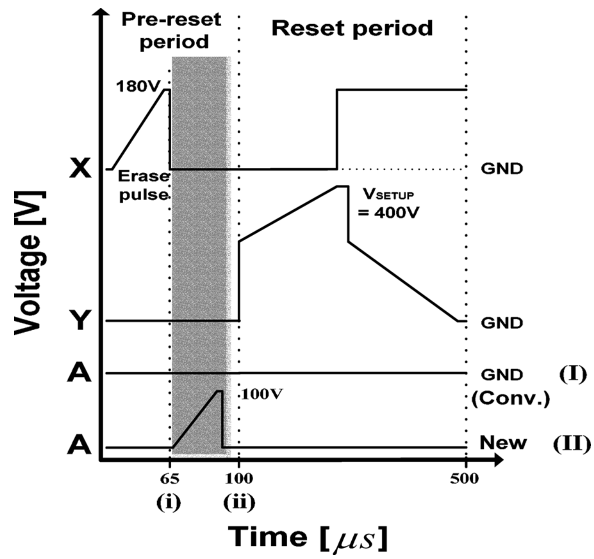


Fig. 6. Ramp-type address prereset waveform for eliminating wall charges accumulated on address electrodes prior to reset-period.

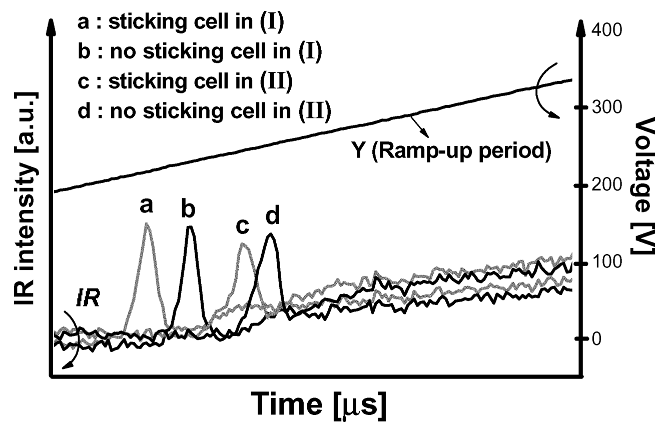


Fig. 7. Changes in IR (828 nm) emissions measured from cells with and without image sticking when applying conventional waveform and ramp-type address prereset waveform.

was because the perception sensitiveness of human eyes is nonlinear, especially under a low background luminance. Essentially, the perceived luminance difference for both types of cell was just slightly reduced, since the perception sensitiveness of the human eyes was intensified due to the low background luminance. In addition, the plate gap reset discharge waveform produced a misfiring discharge due to the unstable reset discharge, presumably as a result of the insufficient initialization caused by the plate gap reset discharge.

2) Elimination of Wall Charges Accumulated on Address Electrode Prior to Reset Discharge: The difference in the amount of wall charges accumulated on the address electrode prior to the reset period between the cells with and without image sticking is another dominant factor causing temporal dark image sticking. Thus, to minimize the difference in the wall charges for both types of cell, a ramp-type pulse was also applied to the address electrode as a prereset pulse between the erase pulse and the ramp-up pulse, as shown in Fig. 6. As such, the ramp-type address pulse was expected to erase the wall charges accumulated on the address electrode prior to the reset-period, thereby minimizing the difference in the wall charges accumulated prior to the reset period between the cells with and without image sticking. Fig. 7 shows the changes in the IR emissions during the ramp-up period for both the cells with and without image sticking when applying the conventional [Fig. 6 (I)] and ramp-type address prereset pulse [Fig. 6 (II)]. In the case of applying the prereset pulse shown by (II) in Fig. 6, the firing voltages for both the cells with and without image sticking were increased, and their IR intensities were also reduced. These changes were induced by the removal of the wall charges accumulated on the address electrode, especially for the image sticking cells, where a lot more wall charges are accumulated due to an iterant strong sustain discharge. However, the firing voltage difference between the cells with and without image sticking was only slightly reduced, indicating that the minimization of the firing voltage difference between the cells with and without image sticking still required a prohibition of the X–Y reset discharge during the ramp-up period, as well as the removal of the wall charges accumulated on the address electrode prior to the reset period. Thus, to investigate the changes in the wall voltage relative to the prereset voltage, the V_t close curve [7], [8] was measured before [Fig. 6 (i)] and after [Fig. 6 (ii)] applying the prereset pulse. As shown in Fig. 8, the firing voltage between the Y–A electrodes (V in Fig. 8) increased in proportion to the increase in the amplitude of the prereset pulse, which meant that a significant amount of the wall charges on the three electrodes, especially the address electrode, prior to the ramp-up period had been erased. Therefore, the result in Fig. 8 indicates that the prereset pulse contributed to alleviating the difference in the ignition time and intensity of the IR between the cells with and without image sticking, even under an activated MgO surface condition.

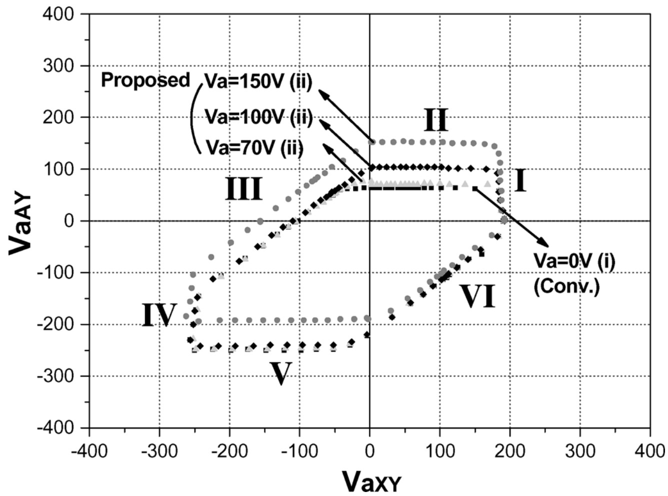


Fig. 8. Changes in V_t close curves relative to amplitudes in proposed ramp-type address prereset waveform, where: I : V_{tXY} (= Discharge start threshold cell voltage between X and Y), II : V_{tAY} (= Discharge start threshold cell voltage between A and Y), III : V_{tAX}(= Discharge start threshold cell voltage between A and X), IV : V_{tYX} (= Discharge start threshold cell voltage between Y and X), V : V_{tYA} (= Discharge start threshold cell voltage between Y and A), and VI : V_{tXA} (= Discharge start threshold cell voltage between X and A).

(a)

(b)

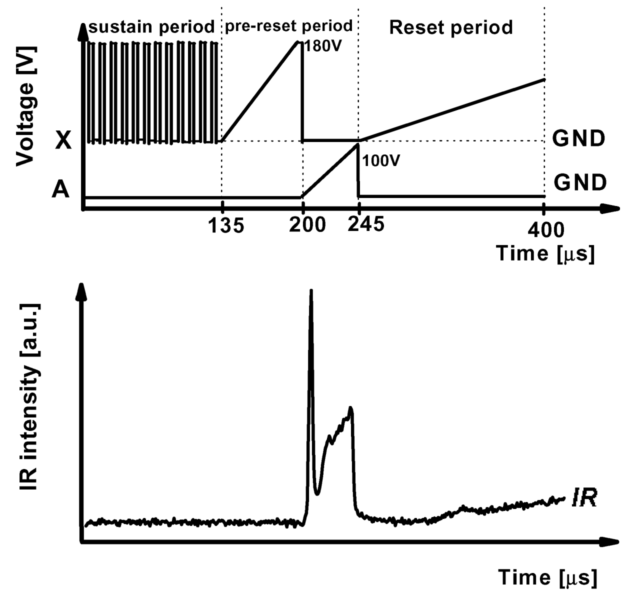


Fig. 10. (b) IR (828 nm) emissions during prereset period when applying (a) proposed driving waveforms in Fig. 9.

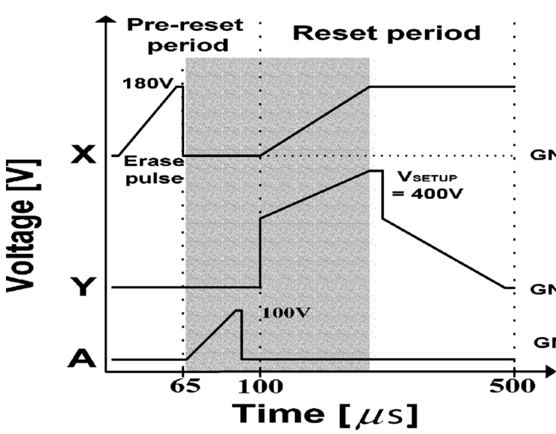


Fig. 9. Proposed driving waveform for reducing temporal dark image sticking (case 2).

(a)

(b)

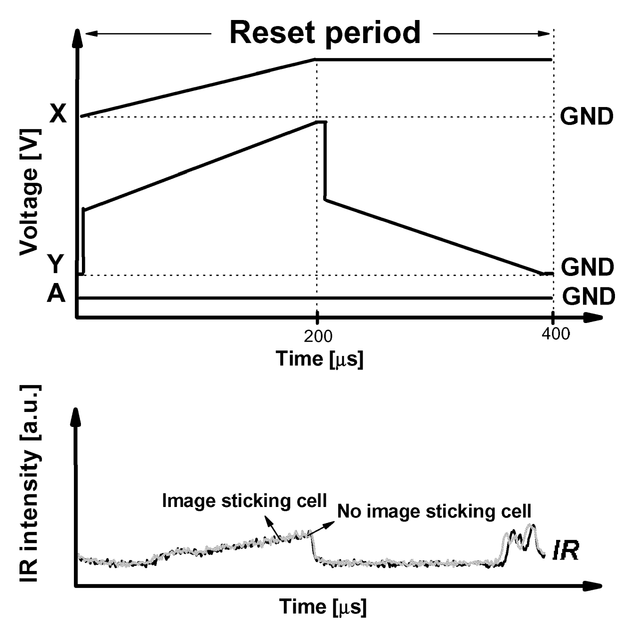
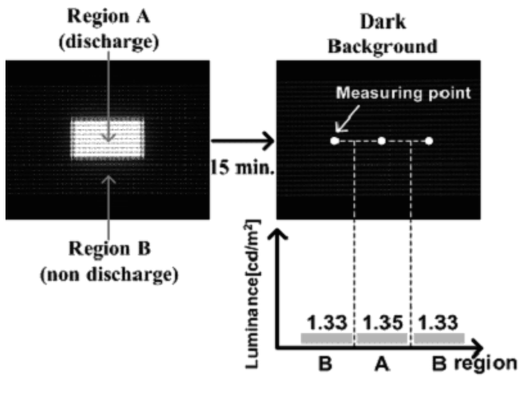


Fig. 11. (a) Proposed driving waveform for reducing temporal dark image sticking and (b) changes in IR (828 nm) emissions measured from cells with and without image sticking when using proposed driving waveform.

B. Proposed Driving Waveform for Reducing Temporal Dark Image Sticking Based on Two Critical Factors

A new driving waveform (case 2) shown in Fig. 9 is proposed to reduce temporal dark image sticking by minimizing the MgO effect in the reset discharge during the ramp-up period after erasing the wall charges accumulated on the address electrode prior to the ramp-up period. The driving waveform in Fig. 9 is thus able to erase the wall charges accumulated on the address electrode prior to the ramp-up period, as shown by the IR emission data in Fig. 10. As a result of the plate gap reset discharge plus the elimination of the wall charges, no difference was observed in the ignition time and intensity of the IR (828 nm) emission waveforms between the cells with and without image sticking, as shown in Fig. 11(b). In this case, the measured display luminance difference, ΔL was considerably reduced to 0.02 cd/m^2, and the perceived luminance differences, ΔP_s and ΔP_d obtained from (1) also considerably reduced to 0.0146 and 0.0548, respectively, as the background luminance in case 2 was slightly increased in comparison with that in case 1. This level is imperceptible to the human eye, as shown in Fig. 12(b). Furthermore, with the proposed waveform, no unstable discharge was observed, although the subsequent address



(a) (b)

Fig. 12. (a) Original square-shaped image pattern and (b) dark background image pattern after displaying original pattern for 15 min when applying proposed driving waveform in Fig. 9.

TABLE I
DIFFERENCE IN PERCEIVED LUMINANCE BETWEEN CELLS WITH AND WITHOUT IMAGE STICKING WHILE DISPLAYING BACKGROUND IMAGE WHEN APPLYING VARIOUS DRIVING WAVEFORMS AND PROPOSED DRIVING WAVEFORM, WHERE $[\mathrm{Va}]_{\min}$ IS MINIMUM ADDRESS VOLTAGE, ΔL IS DISPLAY LUMINANCE DIFFERENCE, AND ΔP IS PERCEIVED LUMINANCE DIFFERENCE

	$[\mathrm{Va}]_{\min}$	L_1 [cd/m^2]	L_2 [cd/m^2]	ΔL [$=L_2-L_1$]	ΔP Standard (ΔP_s) Dark (ΔP_d)
Conv.	52 V	1.99	2.13	0.14	ΔP_s =0.0783
					ΔP_d =0.2879
Case 1	58 V	0.33	0.37	0.04	ΔP_s =0.0669
					ΔP_d =0.2684
Case 2	56 V	1.33	1.35	0.02	ΔP_s =0.0146
					ΔP_d =0.0548
Case 3	54 V	1.30	1.32	0.02	ΔP_s =0.0148
					ΔP_d =0.0556

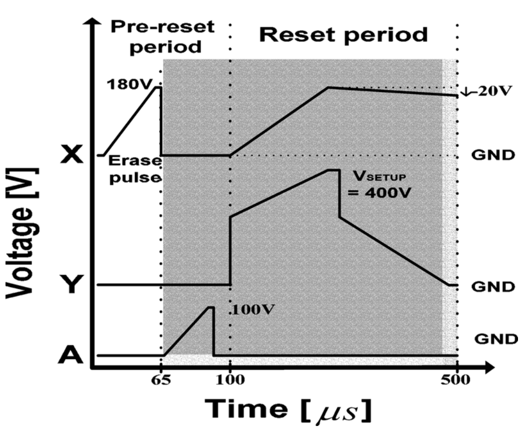


Fig. 13. Proposed driving waveform for improving address characteristics (case 3).

discharge characteristics were slightly deteriorated, as shown in Table I.

C. Improvement of Address Discharge Characteristics Using Negative Ramp Bias in Proposed Driving Waveform Reducing Temporal Dark Image Sticking

Fig. 13 shows the proposed driving waveform, including a negative-going ramp-type X bias, as well as the plate gap reset

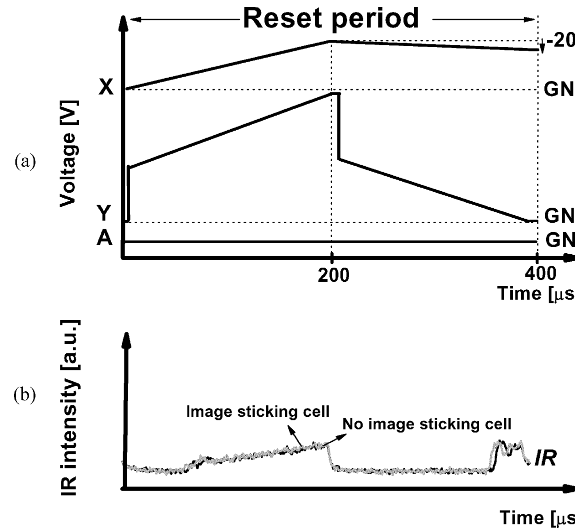
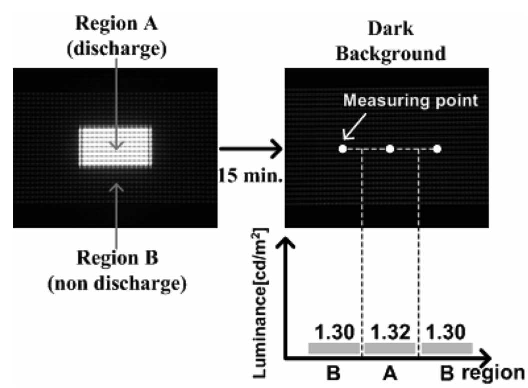


Fig. 14. (a) Proposed driving waveform in Fig. 13 during ramp-period and (b) changes in IR (828 nm) emissions measured from cells with and without image sticking when applying driving waveform in Fig. 13.



(a) (b)

Fig. 15. (a) Original square-shaped image pattern and (b) dark background image pattern after 15-min sustain discharge when applying proposed driving waveform in Fig. 14.

discharge ramp waveform and ramp-type prereset waveform for removing temporal dark image sticking without deteriorating the address discharge characteristics under a low background luminance. With this pulse, a negative-going ramp bias is applied to the common (X) electrode during the ramp-down period, which lessens the erasing of the wall charges on the Y and A electrodes accumulated through the ramp-up period, thereby lowering the background luminance and simultaneously improving the subsequent address discharge characteristics. When adopting the proposed driving waveform in Fig. 13, no difference was observed in the ignition time and intensity of the IR (828 nm) emission waveforms between the cells with and without image sticking, as shown in Fig. 14(b). In a comparison of this case (case 3) with case 2, the address minimum address voltage was decreased about by 2 V, and the background luminance slightly reduced, as shown by the dynamic voltage margin in Fig. 16 and Table I. With case 3, the measured display luminance difference, ΔL was considerably reduced to 0.02 cd/m^2, and the perceived luminance differences, ΔP_s and

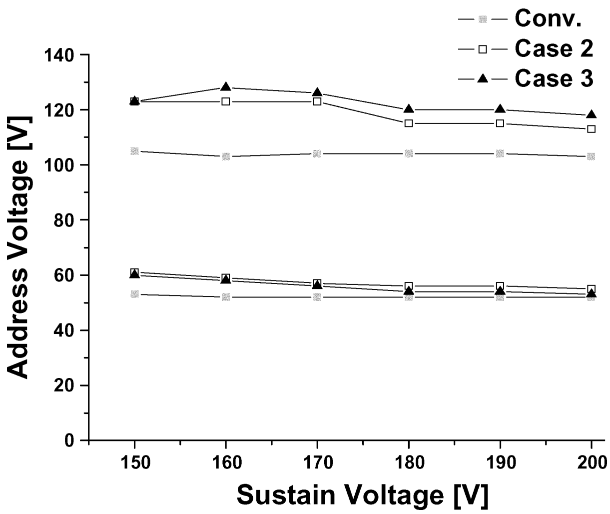


Fig. 16. Comparison of dynamic voltage margins for various driving waveforms, including conventional, and cases 2 and 3.

ΔP_d obtained from (1) also considerably reduced to 0.0148 and 0.0556, respectively. This level is also imperceptible to the human eye, as shown in Fig. 15(b). Accordingly, the proposed driving waveform in Fig. 13 can completely remove temporal dark image sticking without deteriorating the address discharge characteristics.

IV. Conclusion

Temporal dark image sticking is closely related to the reset discharge, which implies that minimizing the X–Y reset discharge produced under an MgO-cathode condition and eliminating the wall charges that accumulate on the address electrode prior to the reset period are the key factors for reducing temporal dark image sticking. Thus, based on the perceived luminance, new driving waveforms that can prohibit an MgO-cathode induced reset discharge or erase the wall charges accumulated on the address electrode prior to the reset period were examined for the complete elimination of temporal dark image sticking without deteriorating the address discharge characteristics. As such, this paper carefully examined three types of driving waveform: a plate gap reset discharge waveform during the ramp-up period, ramp-type address prereset waveform prior to the ramp-period, and negative-going ramp-type X bias during the ramp-down period. Applying the plate gap discharge ramp waveform to the X electrode helped to prohibit the reset discharge under an MgO-cathode condition, the ramp-type address prereset waveform played a role in erasing the wall charges accumulated on the address electrode, and the negative-going ramp-type X bias contributed to improving the address characteristics. As a result of monitoring the difference in the perceived luminance and IR emission between the cells with and without image sticking, the proposed driving waveform that included the plate gap reset discharge ramp waveform, ramp-type prereset waveform, and negative-going ramp-type X bias was shown to effectively remove temporal dark image sticking without deteriorating the address discharge characteristics under a low background luminance.

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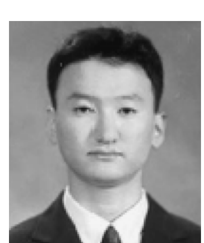
His current research interests include plasma physics and driving waveform of plasma display panels (PDPs).



Byung-Gwon Cho received the B.S. and M.S. degrees in electronic and electrical engineering, in 2001 and 2003, respectively, from Kyungpook National University, Daegu, Korea, where he is currently working toward the Ph.D. degree in electronic engineering.

His current research interests include plasma physics, driving circuit design of plasma display panels (PDPs).

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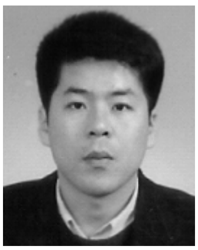

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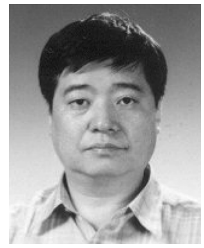

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