

Experimental Observation of Image Sticking Phenomenon in AC Plasma Display Panel

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Abstract—The iterant strong sustain discharge that occurs during a sustain period over a few minutes causes image sticking, which means a ghost image remains in the subsequent image when the previous image was continuously displayed over a few minutes. Accordingly, this paper investigates whether the dominant factor in image sticking is the MgO surface or phosphor layer by testing the effects of image sticking in subsequent dark and bright images using a 42-in plasma display panel. When the subsequent image was dark, the image sticking was found to produce a brighter ghost image than the background. Thus, since the luminance of a dark image is produced by the weak discharge that occurs during the reset-period, the higher luminance of the ghost image was mainly due to the activation of the MgO surface. Conversely, when the subsequent image was bright, the image sticking was found to produce a darker ghost image than the background. Thus, since the luminance of a bright image is predominantly produced by the strong discharge that occurs during the sustain period, the lower luminance of the ghost image was mainly due to the deterioration of the phosphor layer.

Index Terms—Activated MgO surface, brighter ghost image, darker ghost image, deterioration of phosphor layers, image sticking, strong sustain discharge, weak reset discharge.

I. INTRODUCTION

ALTERNATE current plasma display panels (ac-PDPs) are perhaps the most promising candidate for digital high-definition television due to such characteristics as their large surface area (>40 in), slim structure, and self-emitting color image quality. However, there are still several critical issues related to the image quality of plasma display panels that remain to be addressed, such as a low-luminous efficiency [1], dynamic false contours [2], low-color temperatures [3], low gray level contours [4], and image sticking [5]. This paper focuses on the image-sticking problem, which is the residual image or ghost image that remains in a subsequent image when the previous image was continuously displayed over a few minutes. Sometimes, image sticking is also referred to as image retention. It is already known that image sticking is caused by the iterant

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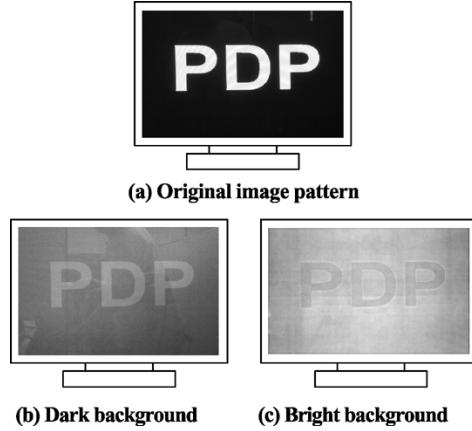


Fig. 1. (a) Original character ‘PDP’ image that was continuously displayed for 4 h., (b) residual character “PDP” image on dark background, and (c) residual character “PDP” image on bright background (c) captured on 42-in PDP-TV.

strong sustain discharge that occurs during the sustain-period when displaying an image. However, the detailed mechanism of image sticking is not yet fully understood.

Accordingly, to determine whether the dominant factor for image sticking is the MgO surface or phosphor layer, the effects of image sticking in dark and bright images were investigated using a 42-in plasma display panel. If image sticking results from the MgO surface, this is related to the discharge current and IR emission. Conversely, if the problem results from the phosphor layer, it is related to the luminance, cell temperature, and color coordinates of the red, green, and blue lights. The current discussion also relates the issue of image sticking to the gray level depending on the respective red, green, and blue cells.

II. EXAMPLES OF IMAGE STICKING PATTERNS IN PLASMA DISPLAY PANELS

As an example of image-sticking patterns, Fig. 1(a) shows the characters “PDP” that were continuously displayed for 4 h on a 42-in PDP-TV. When the “PDP” image was abruptly changed to a completely dark image, the resulting image is shown in Fig. 1(b), which includes a ghost image due to the previous image that still appears as a brighter pattern on the dark background image. Meanwhile, when the “PDP” characters shown in Fig. 1(a) were abruptly changed to a bright pattern, the previous image appears as a darker pattern on the bright background image, as shown in Fig. 1(c).

As an additional example, Fig. 2(a) shows the characters “PLASMA” captured on a 42-in PDP-TV. When continuously

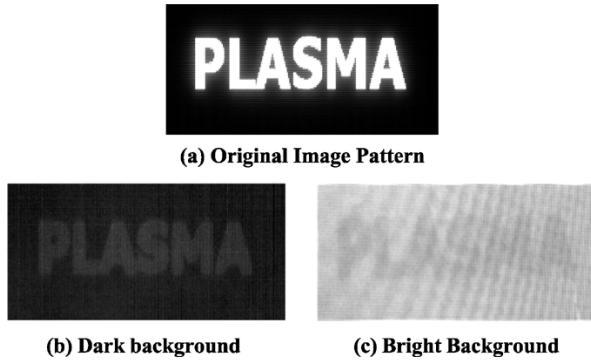


Fig. 2. (a) Original character ‘PLASMA’ image that was continuously displayed for 15 min, (b) residual character ‘PLASMA’ image on dark background, and (c) residual character ‘PLASMA’ image on bright background (c) captured on 42-in PDP-TV.

displayed for just 15 min, the “PLASMA” image still appears in the subsequent dark and bright background images, as shown in Fig. 2(b) and (c), respectively. As the display time of the previous image was only 15 min, the ghost images were less vivid, yet they still appeared.

III. EXPERIMENT

A. Experimental Setup

Fig. 3(a) shows the 42-in. wide video graphics array (WVGA) ac-PDP module with asymmetric stripe barrier ribs and optical measurement systems employed in the experiments. The test patterns used for the image sticking were made by a pattern generator, then transferred into the PDP module by image processing. The luminance and color coordinates of the image appearing on the PDP were measured using a spectrum analyzer (PR-704), while the pattern images and IR waveforms were measured using a digital camera and highly sensitive light detector (Hamamatsu, C6386), respectively.

Fig. 3(b) shows the driving waveforms for the reset, address, and sustain periods when displaying the dark and bright images. While displaying the completely dark image, no address pulse was applied to address electrode A during the address period, as shown in Fig. 3(b). Accordingly, the luminance of the dark image was determined by a weak discharge during the reset period. The maximum voltage of the reset pulse was 390 V and the ramp-up and ramp-down times were 120 μ s and 200 μ s, respectively. Meanwhile, scan and address pulses were simultaneously applied to the scan and address electrodes, Y and A, respectively, only during an address period when the bright background image was displayed. As such, the resultant luminance of the bright image was mainly due to the strong discharge during a sustain period. The amplitude and width of the address pulse were 70 V and 1.2 μ s, respectively. The frequency for the sustain-period was 200 kHz, and the sustain voltage was 176 V. Initialization is important in this experiment. To exclude the effects of the image sticking on the subsequent experiment condition, the ensuing experiments was performed when the cell temperature was returned to the

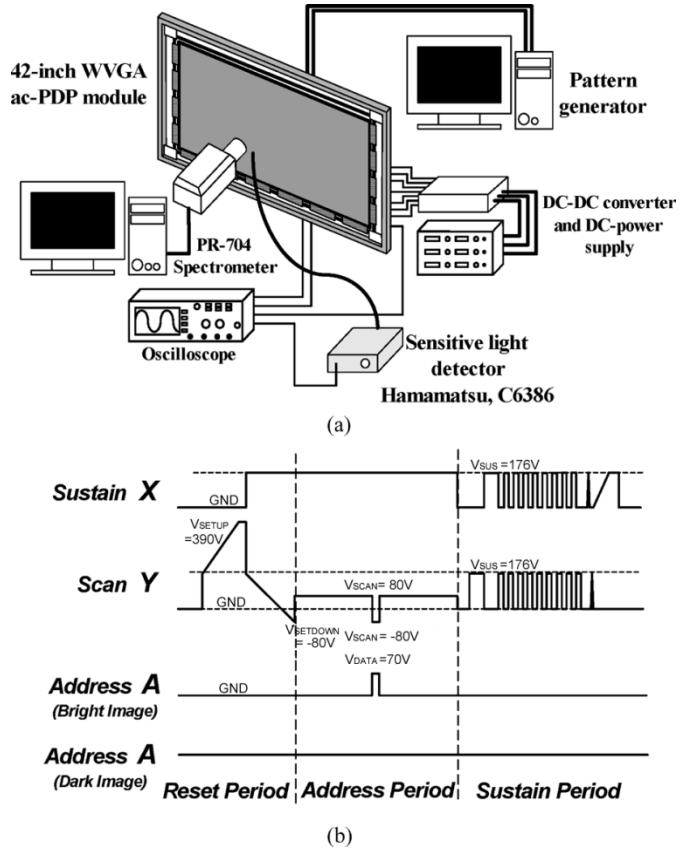
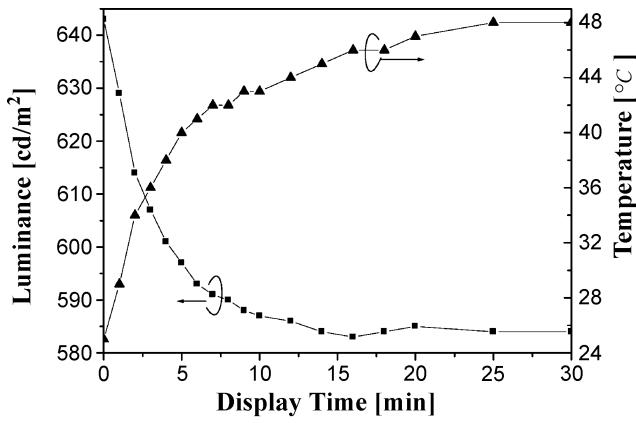


Fig. 3. (a) Optical measurement system employed in current study and (b) driving waveforms for reset, address, and sustain periods for displaying dark and bright images.

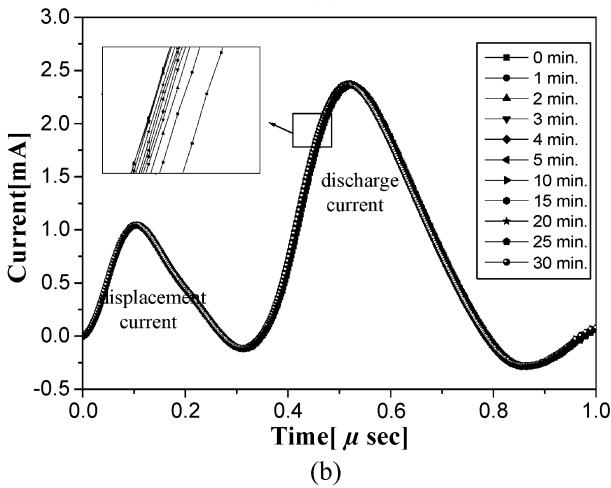
room temperature by continuing the turn-off state of the cells for enough time after displaying the specific patterns.

B. Luminance, Temperature, Discharge Current, and IR Waveform Related to Image Sticking

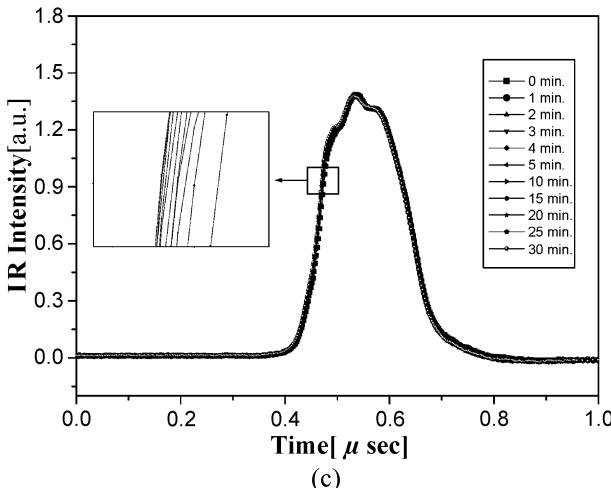
Fig. 4(a) illustrates the changes in the luminance and cell temperature as a function of the display time when the brightest white image was continuously displayed for up to 30 min. Since the sustain discharge continued up to 30 min, the luminance of the white image decreased from 643 to 583 cd/m². As such, the decrease in the luminance during the 30-min sustain discharge was about 60 cd/m². Meanwhile, the cell temperature increased up to 48 °C during the 30-min sustain discharge based on measuring the temperature in front of the glass panel of the PDP, which was also assumed to be the cell temperature. Since the sustain discharge, meaning the discharge produced during the sustain-period, is strong, the iterant strong sustain discharge causes a rise in temperature within a cell even for a short time. Therefore, with a higher temperature (< 50 °C), the iterant strong discharge with charged particles, such as ions and electrons, has a significant influence on the phosphor layer or MgO surface. Accordingly, since the luminance is predominantly determined by the visible conversion of the phosphor layers stimulated by the vacuum ultraviolet (VUV) during the discharge, the



(a)



(b)



(c)

Fig. 4. (a) Luminance degradation and rise in cell temperature, (b) response time of discharge current on sustain electrodes, and (c) response time of IR emission during 30-min sustain discharge under brightest (255 gray level) white image conditions.

luminance decrease in Fig. 4(a) was most likely due to the degradation of the emission characteristics of the phosphor layers as the cell temperature increased.

Fig. 4(b) and (c) shows the changes in the response times of the discharge current on the sustain electrodes and IR emission for different sustain discharge durations. As shown in Fig. 4(b) and (c), the response times of both the discharge current and the IR emission became shorter as the duration of the sustain

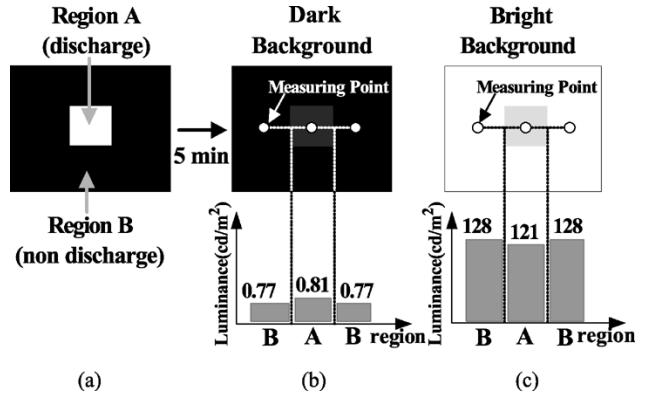
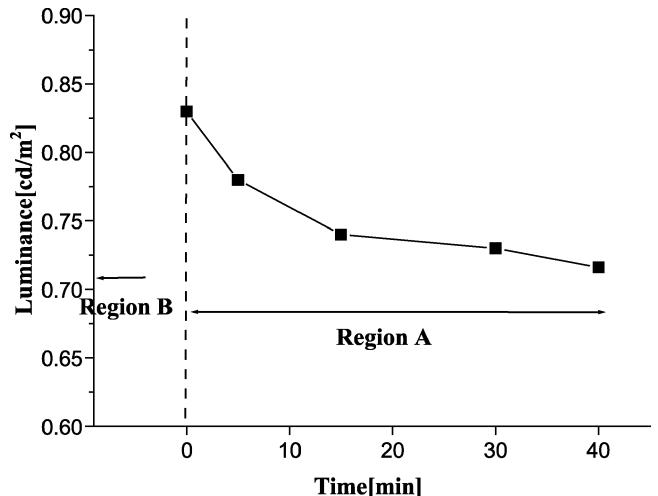
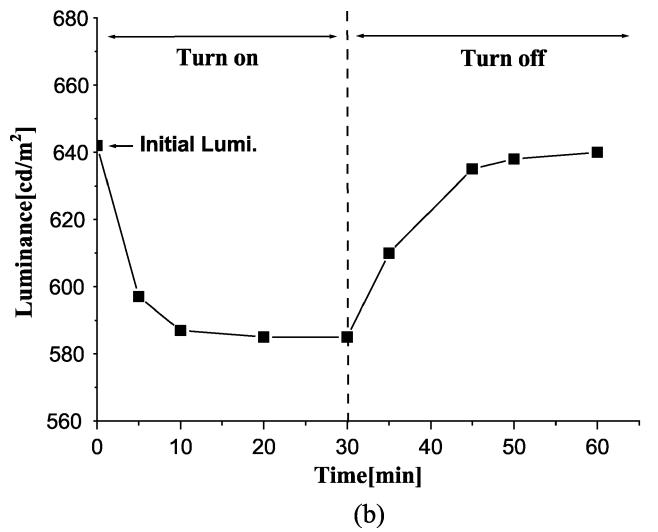


Fig. 5. (a) Square-shaped white image displayed for 5 min at 255 gray levels on dark background, (b) luminance difference between ghost image and dark background, and (c) luminance difference between ghost image and bright background.



(a)



(b)

Fig. 6. (a) Recovery characteristics of temporal dark image sticking under the dark background and (b) recovery characteristics of temporal white image sticking after turn-off state.

discharge increased, indicating that the activation of the MgO surface intensified as the sustain discharge progressed.

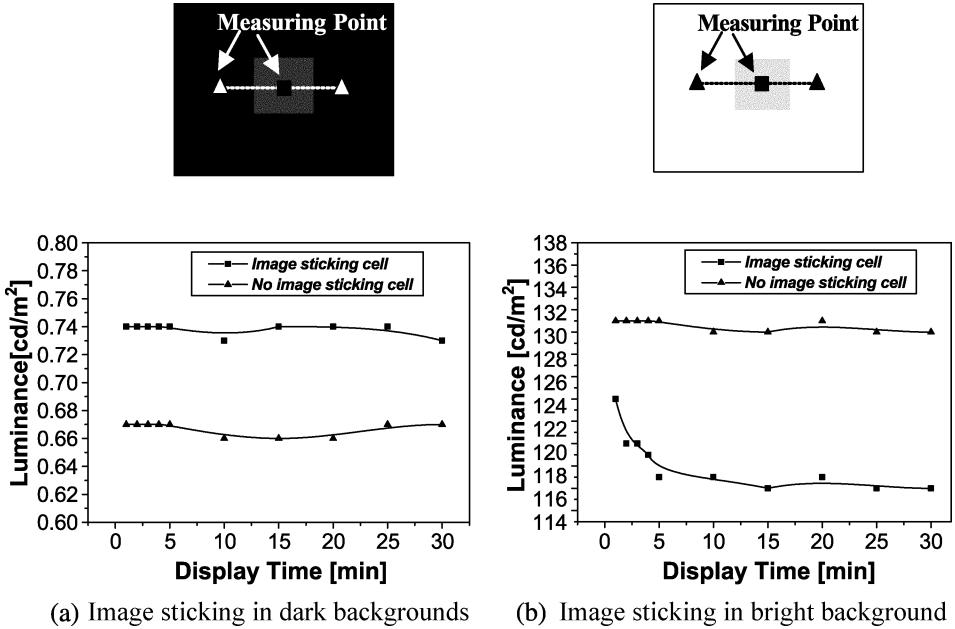


Fig. 7. Luminance difference between image sticking and no image sticking cells for different display times of square-shaped white image in Fig. 5(a), where subsequent background images are (a) dark and (b) bright.

IV. RESULTS AND DISCUSSION

A. Bright and Dark Background Images in Cells With Image Sticking Induced by Iterant Square-Shaped White Image

After a square-shaped white image was displayed for 5 min with 255 gray levels on a dark background, as shown in Fig. 5(a), Fig. 5(b) shows the case where the image was abruptly changed to a completely dark image. As shown in Fig. 5(b), a ghost image of the square still appeared on the dark background image. The luminance difference between the dark background and the ghost image was measured, and the luminance of the ghost image found to be slightly higher, as shown in Fig. 5(b). This higher luminance of the ghost image was most likely caused by the activation of the MgO surface, since the luminance in this case was due to the weak discharge during the rest period. However, when the turn-off state of the cells continued for enough time after 5-min display, the ghost image disappeared. The luminance characteristics were recovered when the cell temperature was returned to the room temperature, meaning that the change in the MgO surface was temporary. The detailed recovery characteristics of the temporal dark image sticking under the dark background are shown in Fig. 6(a). As shown in Fig. 6(a), the luminance difference between the dark background (region A) and the ghost image (region B) became nearly zero after the ghost image was displayed for 40 min under the dark background.

Conversely, when the square image in Fig. 5(a) was abruptly changed to a completely bright image, a darker ghost image still appeared on the bright background image, as shown in Fig. 5(c). Here, the slightly lower luminance of the ghost image was most likely due to the deterioration of the phosphor layer, since the luminance in this case was predominantly determined by the strong discharge during the sustain period. Like the case of Fig. 5(b), when the turn-off state of the cells continued for

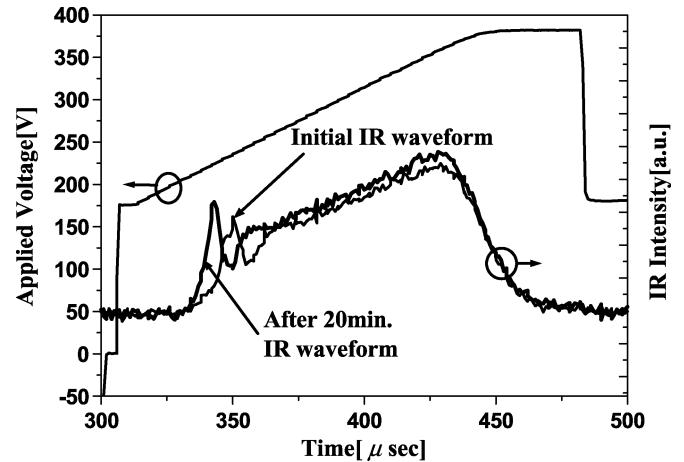


Fig. 8. Change in IR emission during reset period, particularly ramp-up period after square-shaped white image was displayed for 20 min with 255 gray levels.

enough time after 5-min display, the ghost image also disappeared. The luminance characteristics were recovered when the cell temperature was returned to the room temperature, implying that the deterioration in characteristics of phosphor was temporary. The detailed recovery characteristics of the temporal white image sticking are shown in Fig. 6(b). As shown in Fig. 6(b), the decrease in the luminance during the 30-min sustain discharge was recovered completely after the 30-min turn-off state.

Fig. 7(a) and (b) shows more results for different display times of the square-shaped white image in Fig. 5(a). In the case where the subsequent image was completely dark, the upper line in Fig. 7(a) shows the luminance of the ghost image as a function of the display time of the previous image, which was higher than that of the background dark image. As a function of time, the difference in the luminance of the ghost image remained almost consistent up to 30 min. Meanwhile, in the case where the subsequent image was bright, the luminance of the lower line

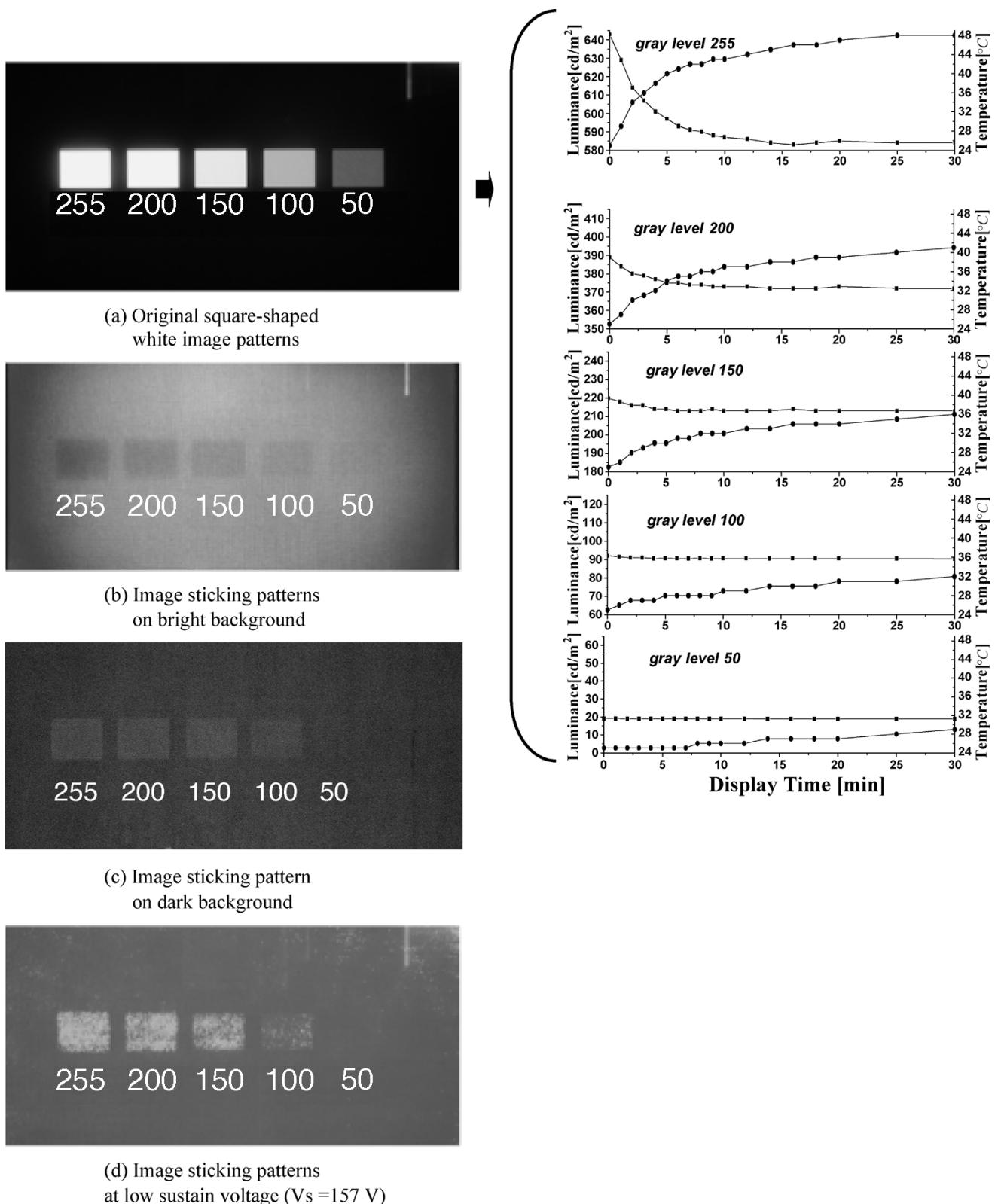


Fig. 9. (a) Original square-shaped white image patterns displayed for 15 min at sustain voltage of 176 V, and luminance degradation and rise in cell temperature with variations in gray levels from 50 to 255 during 30-min sustain discharge, (b) image sticking patterns on bright background, (c) image sticking patterns on dark background, and (d) image sticking patterns at low-sustain voltage ($= 157$ V).

in Fig. 7(b) shows that the luminance of the ghost image was lower than that of the background bright image. In this case, the luminance of the ghost image became lower as the duration of the previous image increased up to 5 min, then remained almost

constant after 5 min. Fig. 8 shows the changes in the IR emission during the reset-period, particularly ramp-up period after the square-shaped white image was displayed for 20 min with 255 gray levels. It was observed that after the 20-min display,

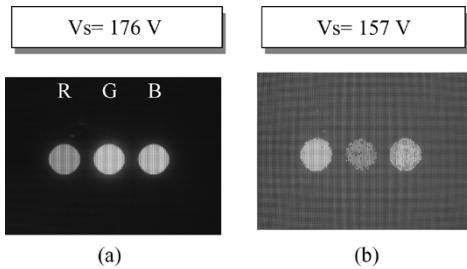


Fig. 10. (a) Original image pattern on dark background in case of applying sustain voltage of 176 V, (b) image pattern in case of applying low-sustain voltage of 157 V on bright background after 5-min display.

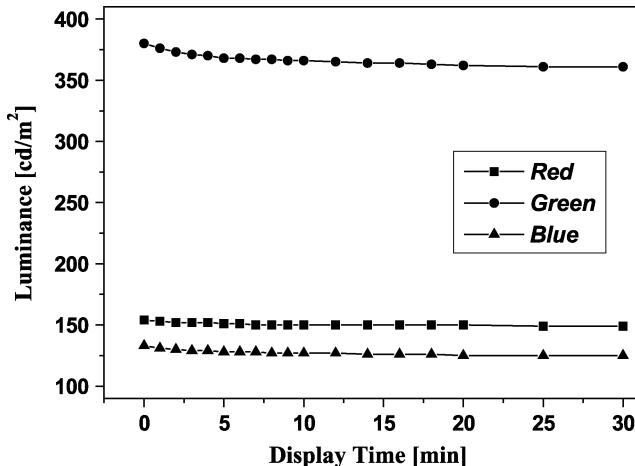


Fig. 11. Luminance degradation of red, green, and blue lights emitted from red, green, and blue cells in Fig. 8(a) relative to display time.

the IR peak was shifted to the left direction and its intensity increased, indicating that the weak reset discharge was initiated efficiently under the low starting discharge voltage. This voltage is closely related with the firing voltage of the cell. Accordingly, since the weak reset discharge strongly depends on the MgO surface, the decrease in the starting discharge voltage at the ramp reset means that the MgO surface is activated during the 20-min display. However, it is not clear that the activation of the MgO surface is directly due to the enhancement of secondary electron emission. This point needs to be further studied.

Fig. 9(a) shows five white square images with different gray levels from 50 to 255, where the images were maintained for 15 min at a sustain voltage of 176 V. As seen on the right side of Fig. 9(a), since the duration of the discharge increased with the gray level, the rise in the cell temperature was more serious in proportion to the gray level, making the decrease in the luminance more serious in proportion to the gray level. When the previous square image patterns in Fig. 9(a) were abruptly changed to a completely bright subsequent image, five ghost images appeared, as shown in Fig. 9(b), with the ghost image of the brightest previous square image appearing as the darkest ghost image. Similarly, when the previous square image patterns in Fig. 9(a) were abruptly changed to a completely dark subsequent image, five ghost images also appeared, as shown in Fig. 9(c), yet in this case, the ghost image of the brightest previous square image appeared as the brightest ghost image. As such, the results in Fig. 9(b) and (c) indicates that the image sticking problem

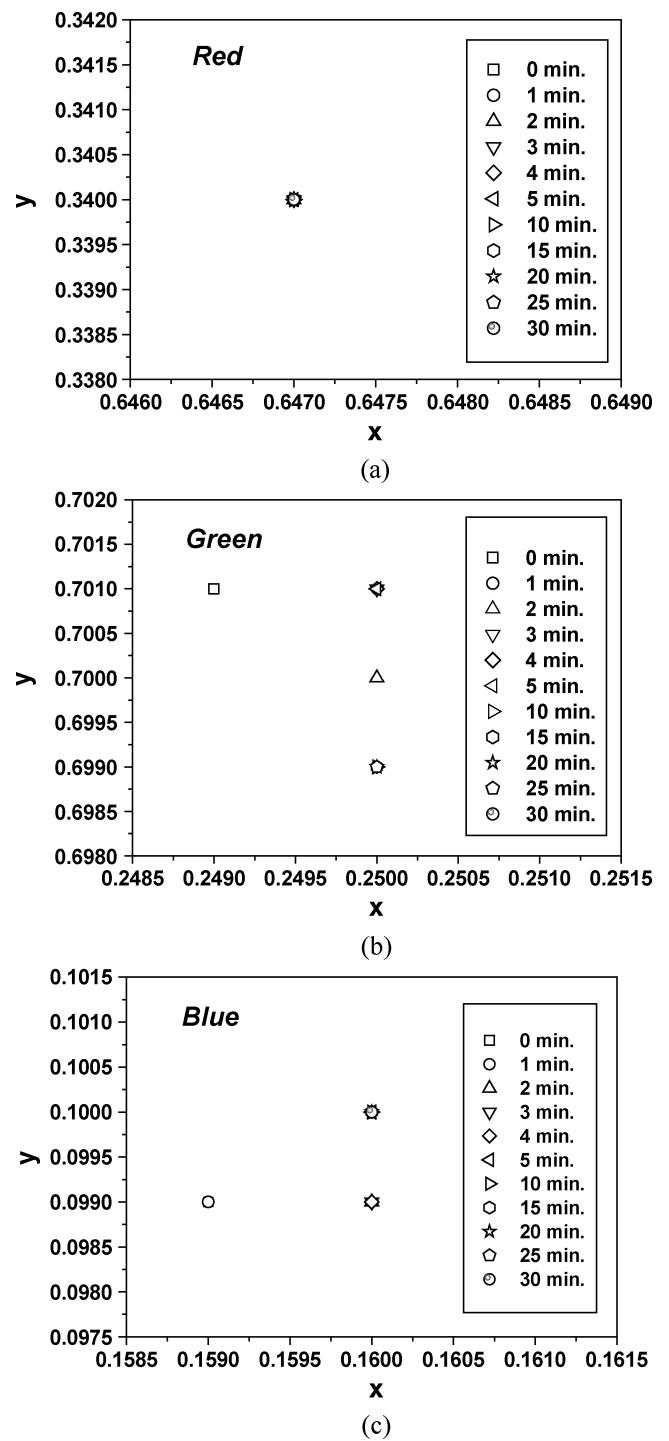


Fig. 12. Changes in color coordinates of red, green, and blue lights relative to display time.

was more serious when the previous image was brighter. Meanwhile, Fig. 9(d) shows the image pattern that appeared when the sustain voltage was abruptly reduced below the minimum sustain voltage on bright background after the previous image in Fig. 9(a) was displayed for 15 min. In the regions with no image sticking, the discharge was completely turned off, as the low voltage, below the minimum sustain voltage, did not produce any discharge. However, the pattern of the previous image, i.e. the ghost image, still remained even at a reduced sustain

voltage of 157 V, indicating a brighter luminance in proportion to the gray level. The discharge in just the image-sticking cells under a low-sustain voltage was presumably due to a change in the MgO surface that was more activated in proportion to the gray level.

B. Image-Sticking Problem Induced by Iterant Circle-Shaped Red, Green, and Blue Images

To investigate an image sticking phenomenon for different phosphor types, circular-shaped red, green, and blue images of Fig. 10(a) were displayed for 5 min at a sustain voltage of 176 V. In the circular area of Fig. 10(a), only the cells with red phosphors were displayed for the red image, only the green cells were displayed for the green image, and only the blue cells were displayed for the blue image. After the 5-min sustain discharge, the sustain voltage was abruptly changed to 157 V on bright background, which is below the minimum sustain voltage. Even though the sustain voltage was insufficient to ignite the sustain discharge, ghost images appeared, as shown in Fig. 10(b). After displaying the red pattern, the bluish ghost image was observed. The deep bluish ghost image occurred after displaying the green pattern, whereas the greenish ghost image appeared after displaying the blue pattern. The color change between the display image and the ghost image for the red, green, and blue patterns illustrates that the adjacent cell of the cell with image sticking can also induce an image sticking problem. This type of boundary image sticking phenomenon needs to be further studied.

Fig. 11 shows that the luminance decreased as the duration of the sustain discharge increased. The reduction in the luminance of the red, green, and blue cells after 30 min was 3.2%, 5%, and 6%, respectively. Fig. 12 compares the initial color purities with the purities after a 30-min discharge. The color purity of the red light was only slightly changed, whereas the color purities of the green and blue lights were deteriorated. As such, the results in Figs. 11 and 12 imply that the deterioration in the emission characteristics of the phosphor layers caused by the sustain discharge depended on the phosphor type.

V. CONCLUSION

In current PDP technology, analyzing the mechanism of image sticking is important for improving the image quality on a PDP. Accordingly, this paper investigated the effects of image sticking on subsequent dark or bright background images using a 42-in plasma display panel. The resulting conclusions are as follows:

- 1) An iterant strong sustain discharge over a few minutes causes an image sticking problem.
- 2) When the subsequent image is dark, image sticking makes a brighter ghost image than the background. In this case, since the luminance of the dark image is only produced by the weak reset discharge, the higher luminance of the ghost image is mainly due to the activation of the MgO surface.

- 3) Conversely, when the subsequent image is bright, image sticking makes a darker ghost image than the background. In this case, since the luminance of the bright image is mainly produced by the strong sustain discharge, the lower luminance of the ghost image is mainly due to the degradation of the phosphor layer.

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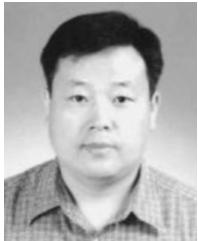
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