PAPER

A Study on Temporal Dark Image Sticking in AC-PDP Using Vacuum-Sealing Method*

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SUMMARY Minimizing the residual impurity gases is a key factor for reducing temporal dark image sticking. Therefore, this paper uses a vacuum-sealing method that minimizes the residual impurity gases by enhancing the base vacuum level, and the resultant change in temporal dark image sticking is then examined in comparison to that with the conventional sealing method using 42-in. ac-PDPs with a high Xe (11%) content. As a result of monitoring the difference in the display luminance, infrared emission, and perceived luminance between the cells with and without temporal dark image sticking, the vacuum-sealing method is demonstrated to reduce temporal dark image sticking by decreasing the residual impurity gases and increasing the oxygen vacancy in the MgO layer. Furthermore, the use of a modified driving waveform along with the vacuum-sealing method is even more effective in reducing temporal dark image sticking.
key words: *42-in. AC-PDP module, vacuum-sealing method, temporal dark image sticking, impurity gas, MgO, sputtering rate, oxygen vacancy, re-deposition, modified driving waveform, IR emission, perceived luminance*

1. Introduction

Despite the suitability of flat panel devices for digital high definition televisions, plasma display panels (PDPs) still suffer from a critical problem known as image sticking, where a residual image appears in a subsequent image when the previous image has been continuously displayed for over a few minutes. When the appearance time of the ghost image is relatively short, this temporal image sticking is also referred to as image retention. Although an iterant strong sustain discharge during a sustain-period is known to induce image sticking, the image sticking phenomenon is still not fully understood [1]–[4]. Accordingly, this paper investigates the temporal dark image sticking problem, also known as dark image retention. As experimental observation has revealed that the base vacuum level is closely related to the temporal dark image sticking phenomenon, the base vacuum level is improved using a vacuum-sealing method, where the front and rear glass panels are sealed in a high vacuum chamber [5], [6]. Thus, the effects of the vacuum-sealing method on the reduction of temporal dark image sticking are examined using 42-in. panels. Furthermore, the impact on temporal dark image sticking of combining the vacuum-sealing method with a modified driving waveform is also investigated based on the perceived luminance, defined as the luminance perceived by human eyes.

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2. Experimental Set-Up for Temporal Dark Image Sticking in AC-PDP

Figure 1 shows the three electrodes, X, Y, and A, in the commercial 42-in. ac-PDP module used to monitor temporal dark image sticking, where the square-shaped image (region B) is the discharge region, and regions A and C are the non-discharge regions. To produce a residual image caused by image sticking, the entire region of the 42-in. panel was abruptly changed to a dark background image after displaying the square-shaped image (region B) at peak luminance (about 1200 cd/m^2) during a 30-second sustained discharge. When the background image was displayed, no address pulses were applied to the address electrodes. In region B, the discharge region, the IR-emissions during the ramp period were measured before and after the 30-second discharge. The cells in region B before the 30-second discharge were non-image sticking cells, whereas after the 30-second discharge the cells became image sticking cells. The luminance was also measured in regions A, B, and C before and after the 30-second discharge using a luminance analyzer (Chroma meter, CA-100 plus) and photosensor amplifier (Hamamatsu, C6386). The 42-in. test panels were fabricated using two different sealing methods, the conventional atmospheric-sealing method and a vacuum-sealing method [5], [6]. Figure 2 shows the conventional driving waveform with a selective reset waveform, including the reset, address,

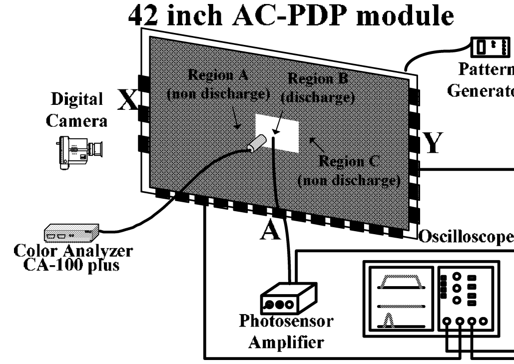


Fig. 1 Schematic diagram of experimental setup employed in this research.

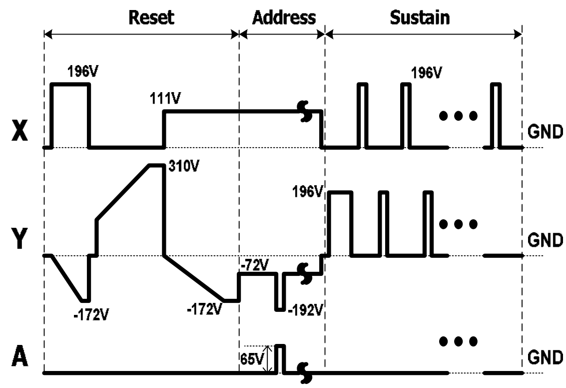


Fig. 2 Schematic diagram of conventional driving waveform used in this study.

Table 1 Specifications of 42-in. AC-PDP used in this study.

Front Panel		Rear Panel	
ITO width	225 μm	Barrier rib width	55 μm
ITO gap	85 μm	Barrier rib height	120 μm
Bus width	50 μm	Address width	95 μm
Pixel Pitch		912 × 693 μm	
Gas chemistry		Ne-Xe (11 %)-He (35 %)	
Barrier rib type		Closed rib	
Red phosphor		$Y(V, P)O_4$, $(Y, Gd)BO_3$	
Green phosphor		Zn_2SiO_4, YBO_3	
Blue phosphor		BAM, CMS	

and sustain periods, employed to compare the temporal dark image sticking of the 42-in. test panels fabricated using the two different sealing methods. The frequency for the sustain period was 200 kHz, and the sustain voltage was 196 V. The gas chemistry in the experiment was Ne-Xe (11%)-He (35%) under a pressure of 430 Torr. The detailed panel specifications for the two cases were exactly the same, except for the sealing process, as listed in Table 1.

3. Experimental Results

Figure 3(b) illustrates the retention of the square-shaped image in the ensuing dark background image immediately after a 30-second sustained discharge (a) in the case of the 42-in. test panel fabricated using the conventional sealing method when applying the conventional driving waveform. Clearly, a ghost image, i.e. the square-shaped image, appeared in the dark background due to a background luminance difference ($\Delta L = 0.02\,\text{cd/m}^2$) between the cells with (after discharge) and without image sticking (before discharge) in region B. As shown in Fig. 3(b), the temporal dark image sticking was measured in terms of the luminance difference between the image sticking and non-image sticking cells. However, when dealing with dark image sticking, the luminance perceived by human eyes should considered instead of the measured display luminance, as the final evaluation of dark image sticking is made based on human perception. The relation between the perceived luminance, P and the

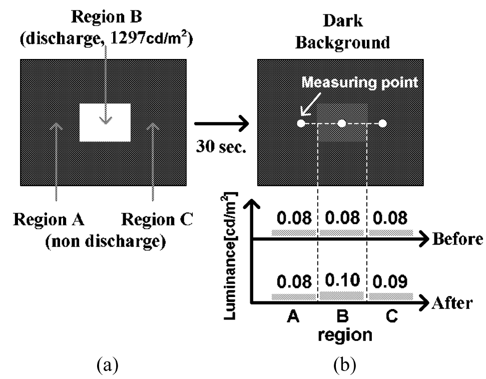


Fig. 3 (a) Original image pattern and (b) residual (or ghost) square-shaped pattern when displaying dark background captured from 42-in. panel fabricated using conventional sealing method when applying conventional reset waveform (Conv.).

Table 2 Difference in perceived luminance measured from region B with and without image sticking while displaying background image when applying conventional and modified driving waveform from 42-in. panel fabricated using conventional and vacuum-sealing method, where ΔL is display luminance difference, and ΔP is perceived luminance difference.

	L_1 [cd/m²]	L_2 [cd/m²]	ΔL $[=\lvert L_2-L_1\rvert]$	ΔP
				Standard (ΔP_s)
				Dark (ΔP_d)
Conv.	0.08	0.10	0.02	ΔP_s=0.0776
				ΔP_d=0.3327
Vacuum 1	0.29	0.27	0.02	ΔP_s=0.0384
				ΔP_d=0.1557
Vacuum 2	0.19	0.18	0.01	ΔP_s=0.0248
				ΔP_d=0.1027

display luminance, $L\,[\text{cd/m}^2]$ is as follows [2]:

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

Consequently, for the standard case, the perceived luminance difference, ΔP_s $(= P_2 - P_1)$ for the standard state was 0.0776. Meanwhile, for the dark case, the perceived luminance difference, ΔP_d $(= P_2 - P_1)$ for the dark state was 0.3327, as shown in Table 2.

Figure 4 shows the changes in the IR (828 nm) emissions measured from region B with and without image sticking for the 42-in. test panel fabricated using the conventional sealing method when applying the conventional driving waveform during a reset period. As shown in Fig. 4, for the image sticking cells, the IR emission was observed to shift to the left. Plus, as shown in Table 3, in the conventional sealing case, the temporal dark image sticking disappeared after about 40 seconds.

The vacuum-sealing method was adopted to enhance the base vacuum level and thereby minimize the residual impurity gases. Figure 5(b) illustrates the retention of the square-shaped image in the ensuing dark background image immediately after a 30-second sustained discharge

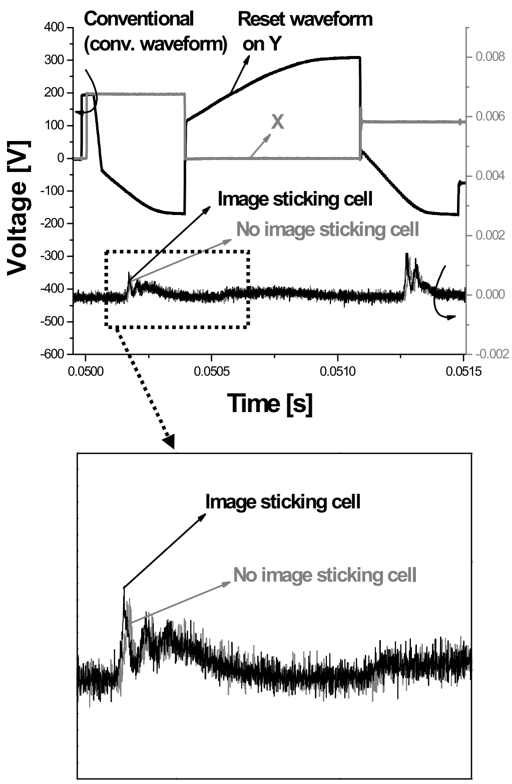


Fig. 4 Changes in IR (828 nm) emissions measured from region B with and without image sticking when applying conventional reset waveform from 42-in. panel fabricated using conventional sealing method.

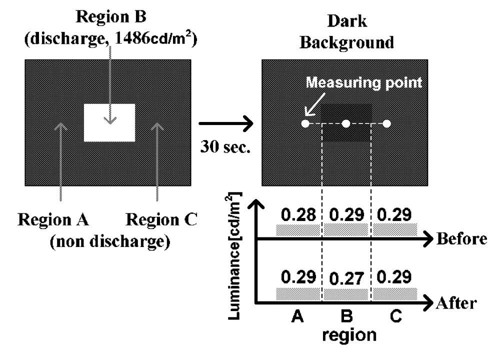
Table 3 Difference in disappeared time of temporal dark image sticking measured from region B with and without image sticking while displaying background image when applying conventional and modified driving waveform from 42-in. panel fabricated using conventional and vacuum-sealing method.

	Disappearing time of temporal dark image sticking [second]
Conv.	40
Vacuum 1	10
Vacuum 2	5

(a) for the 42-in. test panel fabricated using the vacuum-sealing method when applying the conventional driving waveform. Although a ghost image did appear in the dark background due to a background luminance difference ($\Delta L = 0.02\,\text{cd/m}^2$) between the cells with and without image sticking in region B, the perceived luminance differences, ΔP_s and ΔP_d were considerably reduced to 0.0384 and 0.1557, respectively, as shown in Table 2. This was because the perception sensitivity of human eyes is non-linear, especially in the case of a low background luminance. Although the luminance difference between the image sticking and non-image sticking cells in the 42-in. test panels fabricated using the conventional and vacuum-sealing methods were almost the same, the perceived luminance differences with the vacuum-sealing method were lower than those with the conventional sealing method, as the human-eye perception sensitivity was reduced due to the higher background luminance [2]. However, a lower background luminance does not automatically mean a lower perceived luminance difference, as this is mainly determined by the background luminance difference, and not by the background luminance itself. In PDP cells, the background luminance difference between image sticking and non-image sticking cells is increased in proportion to the background luminance of the image sticking cells. To obtain a higher background luminance, a higher voltage is required, which can result in damage to the MgO surface due to the stronger ion bombardment.

Figure 6 shows the changes in the IR (828 nm) emissions measured in region B with and without image sticking for the 42-in. test panel fabricated using the vacuum-sealing method when applying the conventional driving waveform during the reset period. As shown in Fig. 6, for the image sticking cells, the IR emission was also observed to shift to the left. However, in the case of the vacuum-sealing, the IR emissions were intensified when compared to those with the conventional sealing method at the same voltage, plus the temporal dark image sticking disappeared after about 10 seconds (cf. in the case of the conventional sealing, the temporal image sticking disappeared after about 40 seconds), as shown in Table 3.

When using the conventional sealing method, the luminance of the cells with image sticking was higher than that of the cells without image sticking in region B, as shown in Fig. 3. In contrast, when using the vacuum-sealing method, the luminance of the cells with image sticking was lower than that of the cells without image sticking in region B, as shown in Fig. 5. The IR-emission data shown in Fig. 6 also revealed that the IR peak for the cells with image sticking was intensified compared to that for the cells without image sticking in region B. However, the luminance characteristic of the cells with image sticking in region B deteriorated with the dark background. While the IR-emission characteristics are closely related to the MgO surface, the luminance characteristics are more related to the visible-conversion capability of the phosphor layer. Consequently,



(a) (b)

Fig. 5 (a) Original image pattern and (b) residual (or ghost) square-shaped pattern when displaying dark background captured from 42-in. panel fabricated using vacuum-sealing method when applying conventional reset waveform (Vacuum 1).

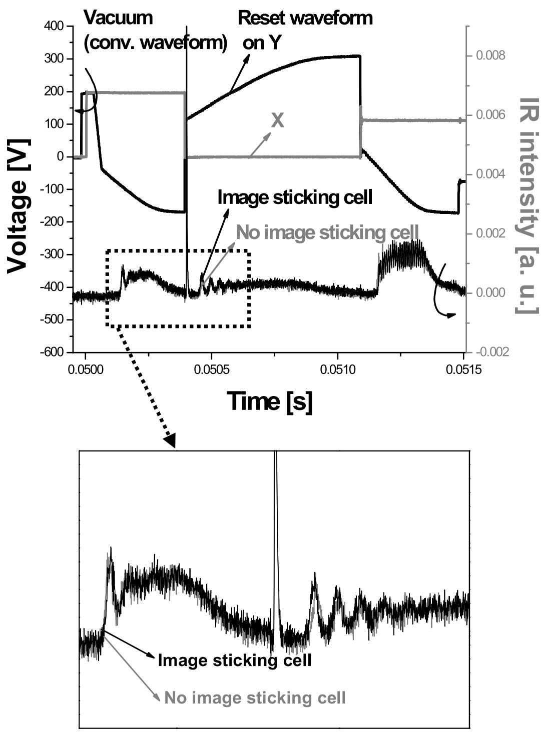


Fig. 6 Changes in IR (828 nm) emissions measured from region B with and without image stickings when applying conventional reset waveform from 42-in. panel fabricated using vacuum-sealing method.

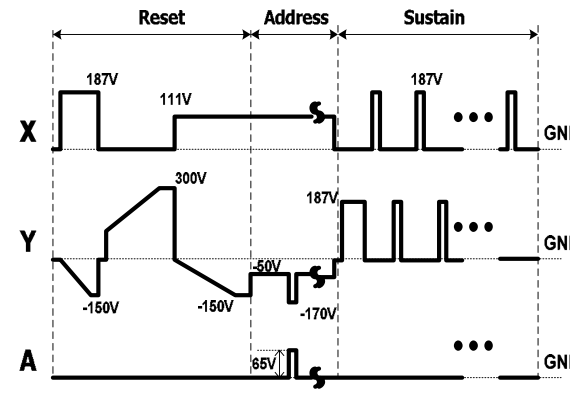


Fig. 7 Modified driving waveform for reducing temporal dark image sticking from 42-in. panel fabricated using vacuum-sealing method.

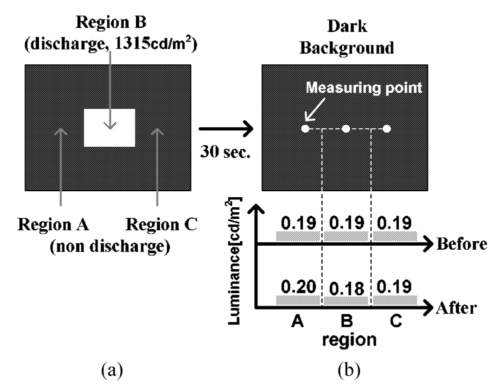


Fig. 8 (a) Original image pattern and (b) residual (or ghost) square-shaped pattern when displaying dark background captured from 42-in. panel fabricated using vacuum-sealing method when applying modified reset waveform (Vacuum 2).

the data in Figs. 5 and 6 indicated that the discharge characteristics were improved in the cells with image sticking in region B, whereas the visible-conversion characteristics were aggravated [3].

In the case of the conventional sealing method, the front and rear glass panels are sealed at a high temperature under atmospheric pressure, allowing lots of oxygen to be included. However, with the vacuum-sealing method, the front and rear glass panels are sealed at a high temperature in a high vacuum, allowing only a small amount of oxygen to be included. Consequently, the oxygen vacancy in the MgO layer with the vacuum-sealing method is much higher than that with the conventional sealing method [7], [9]. Thus, the reduction in the luminance of the cells with image sticking in region B was mainly due to the increased MgO sputtering rate with the vacuum-sealing method, resulting from the higher the oxygen vacancy in the MgO layer [4], [7]–[9]. Therefore, the decrease in the luminance of the cells with image sticking in region B was attributed to the temporary prohibition of a visible conversion from the vacuum ultraviolet (VUV) of the phosphor layers caused by MgO deposition onto the phosphor layers [3]. Furthermore, it is also expected that the Mg species of the sputtered MgO layer were more easily recovered with the vacuum-sealing method than the conventional sealing method, due to the higher sputtering rate of the MgO layer [7], [9]. Therefore, these results indicate that the vacuum-sealing method was able to reduce temporal dark image sticking by decreasing the residual impurity gases and increasing the oxygen vacancy in the MgO layer.

In the case of vacuum sealing, since the firing voltage was observed to be reduced and the secondary electron coefficient for the MgO layer found to be increased [5], [6], [10], the conventional driving waveform in Fig. 2 needed to be modified. Thus, a modified driving waveform, as shown in Fig. 7, was proposed to further reduce the temporal dark image sticking on the 42-in. test panel fabricated using the vacuum-sealing method based on minimizing the MgO effect in the reset and sustain discharges. As shown in Fig. 7, the modified driving waveform has lower voltage levels than the conventional driving waveform in Fig. 2.

Figure 8(b) illustrates the retention of the square-shaped image in the ensuing dark background image immediately after a 30-second sustained discharge (a) with the 42-in. test panel fabricated using the vacuum-sealing method when applying the modified driving waveform. In this case, the measured display luminance difference, ΔL was reduced to 0.01 cd/m^2, while the perceived luminance differences, ΔP_s and ΔP_d were considerably reduced to 0.0248 and 0.1027, respectively, as shown in Table 2. Also, when applying the modified driving waveform, no difference was observed in the ignition time and intensity of the IR (828 nm)

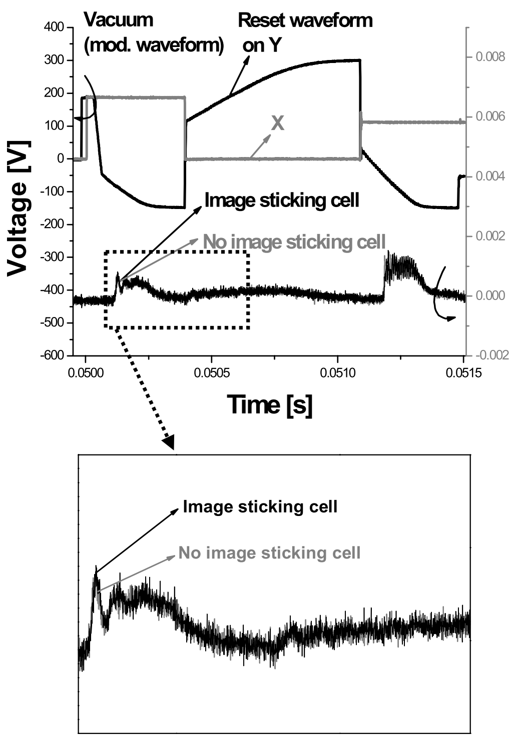


Fig. 9 Changes in IR (828 nm) emissions measured from region B with and without image sticking when applying modified reset waveform from 42-in. panel fabricated using vacuum-sealing method.

emission waveforms between the cells with and without image sticking, as shown in Fig. 9, and the temporal dark image sticking disappeared after about 5 seconds, as shown in Table 3. Therefore, it is expected that these experimental results will help to reduce the problem of temporal dark image sticking in PDP-TVs.

4. Conclusions

A vacuum-sealing method to enhance the base vacuum level was adopted to minimize the residual impurity gases, and the resultant change in temporal dark image sticking examined in comparison with the conventional sealing method using 42-in. ac-PDPs with a high Xe (11%) content. As a result of monitoring the difference in the display luminance, infrared emission, and perceived luminance between the cells with and without image sticking, the vacuum-sealing method was able to reduce the temporal dark image sticking by decreasing the residual impurity gases and increasing the oxygen vacancy in the MgO layer. Furthermore, the use of a modified driving waveform along with the vacuum-sealing method was even more effective in reducing temporal dark image sticking. Thus, it is expected that these experimental results will help reduce the problem of temporal dark image sticking in PDP-TVs.

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