Improvement of Temporal Image Sticking Characteristics Using Negative Sustain Waveform in AC Plasma Display Panel

Choon-Sang Park, Jae Hyun Kim, Heung-Sik Tae, *Senior Member, IEEE*, and Sung-Il Chien

***Abstract*—Temporal image sticking characteristics on the bright screen produced by a negative sustain waveform were examined in comparison with those produced by a positive sustain waveform. From the monitoring of the differences in the display luminance, chromaticity coordinate, color temperature, infrared emission, and address current between the cells with and without temporal image sticking, it was observed that the negative sustain waveform contributed to the reduction of temporal image sticking. When applying the negative sustain waveform, ion bombardment of the phosphor layer was minimized during a sustain discharge, thereby reducing the absorption of H_2O onto the phosphor layers, as confirmed by thermal desorption spectroscopy and photoluminescence analyses. As a result, the temporal image sticking characteristics were improved, mainly due to less degradation of the visible conversion and fewer changes of the characteristics of the phosphor layer by diminishing the absorption of H_2O onto the phosphor layer.**

***Index Terms*—Absorption, hydrate, H_2O, negative sustain waveform, photoluminescence, plasma display panel (PDP), temporal image sticking, thermal desorption spectroscopy (TDS), visible conversion characteristics of phosphor layer.**

I. Introduction

IMAGE STICKING problems of current plasma display panels (PDPs) still need to be improved in order to realize high-quality Internet protocol televisions, Smart TVs, public information displays, and electronic copy boards. Nonetheless, the temporal image sticking or image retention problems of PDPs remain as a significant defect compared with those of other display devices. While this phenomenon of temporal image sticking is essentially related to deterioration of the MgO surface or phosphor layer during a strong sustain discharge, its detailed mechanism is not still clearly understood [1]–[9]. Temporal image sticking is recoverable, and as such, the changes in the surface states such as an MgO or phosphor layer in temporal image sticking cells are minor. This means that it is very difficult to measure precisely the changes in the surface states of the MgO or phosphor layers induced as a result of temporal image sticking phenomenon. Experiments by current authors have shown that the degradation of the visible conversion of the phosphor layer caused by the absorption of H_2O onto the phosphor layer induces temporal bright image sticking (or temporal dark image sticking on the bright screen), which would be intensified by ion bombardment of the phosphor layer during a sustain discharge [1], [2]. Thus, it is expected that suppressing the ion bombardment of the phosphor layer during a sustain discharge would contribute to reducing the temporal bright image sticking. In the previous related research, by blocking the ion bombardment of the phosphor layer, the address waveform was directly applied to the address electrode during the sustain period [2]. As a result, the absorption of H_2O onto the phosphor layer was effectively minimized, thereby resulting in the reduction of temporal bright image sticking [2]. However, the effect of the sustain waveform on both the temporal bright image sticking and the absorption of H_2O onto the phosphor layer has not been examined so far, even though several efforts to reduce temporal bright image sticking have been reported, such as positive-biased address electrode, vacuum sealing method, auxiliary electrode, high He contents, and etc. [1]–[9]. In this sense, the negative sustain waveform [10]–[12] is considered to be suitable for reducing the temporal bright image sticking because it can minimize ion bombardment of the phosphor layer during a sustain discharge.

Accordingly, in order to reduce the ion bombardment on the phosphor layers during the sustain discharge by modifying the sustain waveform, this paper investigates in detail the influences of the negative sustain waveform on the temporal bright image sticking problems, also known as image retention in ac-PDP. The conventional positive sustain waveform was employed as a reference waveform. For two different sustain waveforms such as the conventional positive and proposed negative sustain waveforms, the differences in the display luminance, chromaticity coordinate, color temperature, infrared (IR) emission, and address current were monitored before and after 5-min sustain discharge. In particular, to investigate a main mechanism responsible for inducing temporal bright image sticking for both sustain waveforms, the absorption of H_2O onto the phosphor layer and the photoluminescence (PL) intensity (380–780 nm) of the phosphor layer were examined by using the thermal desorption spectroscopy (TDS) and PL analyses, respectively.

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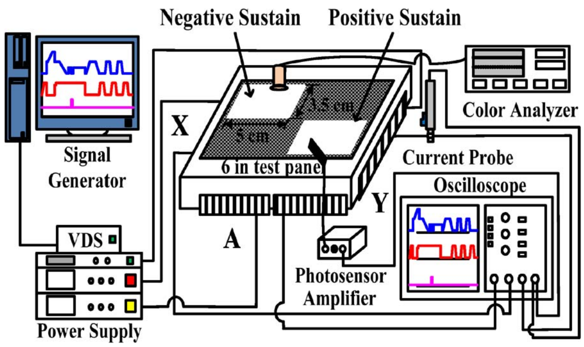


Fig. 1. Schematic diagram of optical and electrical measurement systems used to measure luminance, chromaticity coordinate, color temperature, IR emission, and address current in this research.

TABLE I
SPECIFICATIONS OF 6-IN AC-PDP USED IN THIS STUDY

Front Panel		Rear Panel	
ITO width	220 μm	Barrier rib width	50 μm
ITO gap	80 μm	Barrier rib height	125 μm
Bus width	50 μm	Address width	90 μm
Pixel Pitch		912 μm × 693 μm	
Gas chemistry		Ne-Xe (10 %)	
Pressure		420 Torr	
Barrier rib type		Closed rib	

II. EXPERIMENTAL SETUP

Fig. 1 shows a schematic diagram of the optical and electrical measurement system used in this study, where X is the sustain electrode, Y is the scan electrode, and A is the address electrode. The 6-in high-definition (HD) ac-plasma display test panel was used to monitor the temporal image sticking, where the square-shaped pattern was the discharge region and other region was the nondischarge region. A color analyzer (CA-100), versatile driving simulator, photosensor amplifier (Hamamatsu C6386), current probe (AP015), and signal generator were used to measure the luminance, CIE (1931) chromaticity coordinate, color temperature, IR emission, and address current, when applying the two different sustain waveforms such as the positive and negative sustain waveforms to the test panel, respectively. The induced temporal image sticking was measured by changing the entire region of the 6-in panel to the white background immediately after a square-type image (discharge region) was displayed for 5 min. The gas compositions and working pressure in the 6-in HD AC-PDP test panel were Ne-Xe (10%) and 420 Torr, respectively. The detailed specifications for the 6-in test panel are listed in Table I.

Fig. 2 shows the two different sustain waveforms employed to investigate the influences of types of sustain waveform on inducing the temporal image sticking where a) is the conventional positive waveform (ref.) and b) is the proposed negative waveform. In Fig. 2, the voltage levels were fixed at 200 V for positive sustain pulse and −200 V for negative sustain pulse. The frequency and the duty ratio for sustain period were 200 kHz and 50%, respectively.

The mass intensity of H_2O adsorbed in the phosphor layer was measured by using the TDS (ESCO, EMD-WA1000S/W) analysis shown in Fig. 3. When the sample is heated by using the IR lamp in the vacuum chamber with 10^{-6} Torr, the gas

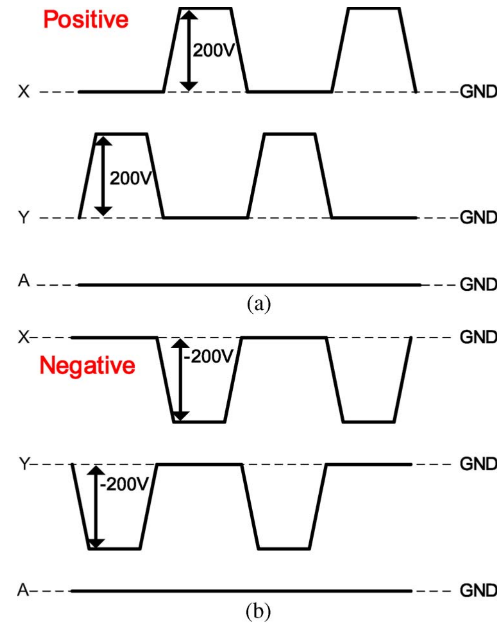


Fig. 2. Two different sustain waveforms employed to investigate influences of shape of sustain waveform on inducing temporal image sticking: (a) conventional positive (ref.) waveform and (b) proposed negative waveform.

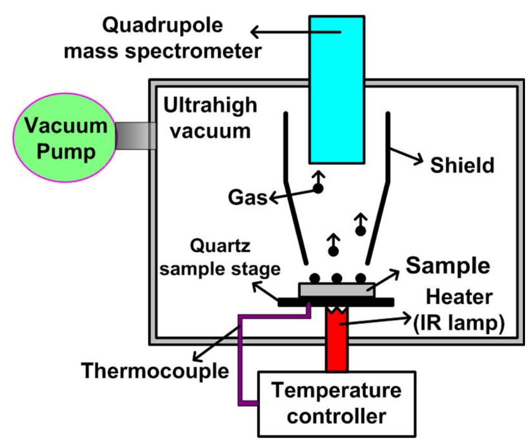


Fig. 3. Schematic diagram of thermal desorption spectroscopy system.

desorbed from the heated sample was detected by using the quadrupole mass spectrometer. Here, the heated temperature was ranged from 60 °C to 580 °C.

III. EXPERIMENTAL OBSERVATION ON TEMPORAL IMAGE STICKING FOR POSITIVE AND NEGATIVE SUSTAIN WAVEFORMS

A. *Monitoring of Luminance*

Fig. 4 shows the changes in the luminance and luminance difference in the discharge region with a full-white background measured before and after a 5-min discharge when applying the positive and negative sustain waveforms to the sustain electrodes. In Fig. 4, the luminance after a 5-min discharge was reduced for both sustain waveforms. However, with the negative sustain waveform, the luminance was slightly decreased, even though the initial luminance was higher. The reduction of the luminance difference after the 5-min sustain discharge indicated

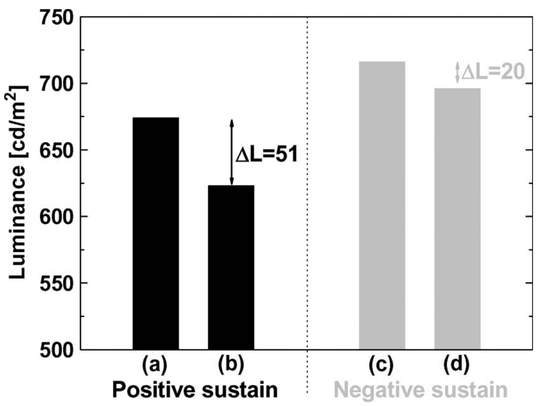


Fig. 4. Changes in luminance and luminance difference ($= \Delta L$) measured [(a) and (c)] before and [(b) and (d)] after 5-min sustain discharge in discharge region when applying positive and negative sustain waveforms to sustain electrodes.

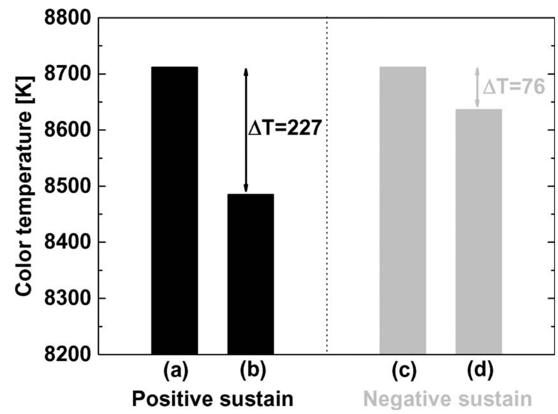


Fig. 6. Changes in color temperature and color temperature difference ($= \Delta T$) measured [(a) and (c)] before and [(b) and (d)] after 5-min sustain discharge in discharge region when applying positive and negative sustain waveforms to sustain electrodes.

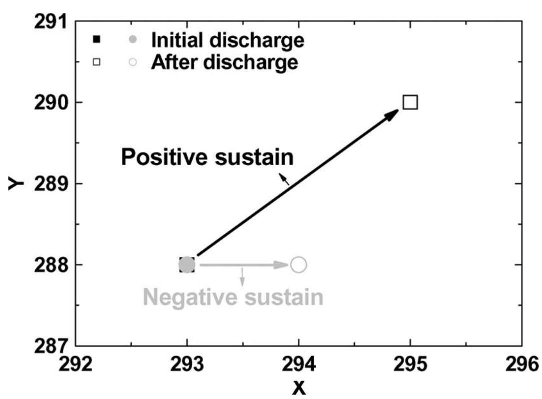


Fig. 5. Changes in CIE (1931) chromaticity coordinates measured before and after 5-min sustain discharge in discharge region when applying positive and negative sustain waveforms to sustain electrodes.

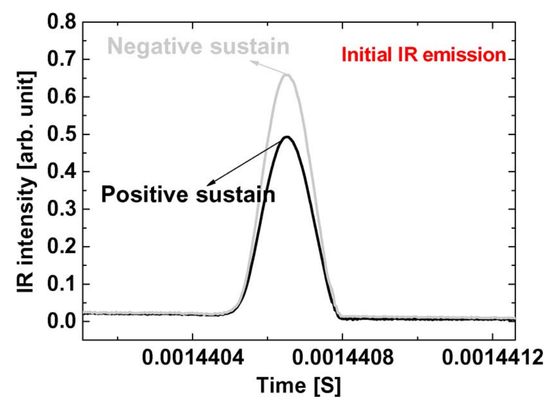


Fig. 7. Changes in IR emission waveforms during initial sustain discharge when applying positive and negative sustain waveforms to sustain electrodes.

that the negative sustain waveform contributed to suppressing the temporal image sticking. In addition, in the case of adopting the negative sustain waveform, the initial luminance was higher, implying that the negative sustain waveform also contributed to improving the luminous efficiency [10].

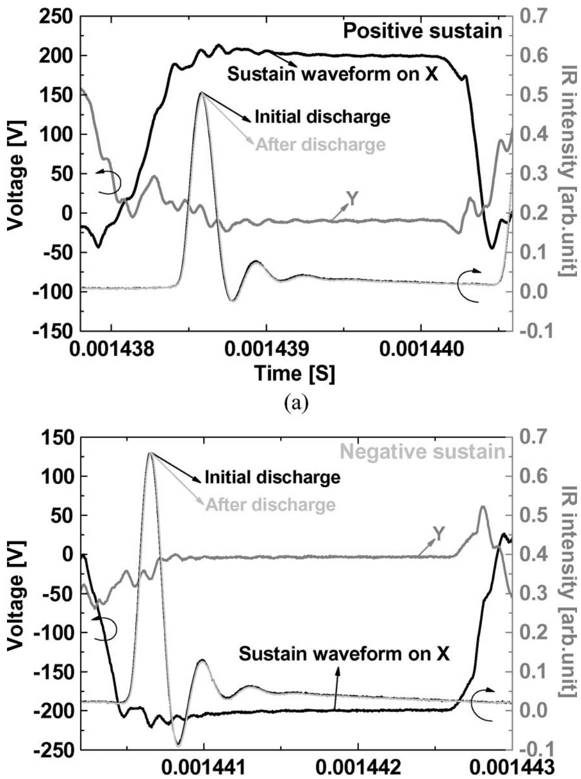
B. Monitoring of Chromaticity Coordinate and Color Temperature

The temporal image sticking phenomenon is known to be strongly related to activation of the phosphor layer. As such, the changes in the International Commission on Illumination CIE (1931) chromaticity coordinates and related color temperatures were measured under a full-white background at both before and after a 5-min sustain discharges when applying the positive and negative sustain waveforms to the sustain electrodes, respectively. As shown in Figs. 5 and 6, with the positive sustain waveform, the chromaticity coordinates x and y were changed as a result of the 5-min sustain discharge, thereby resulting in deteriorating the color temperature. However, with the negative sustain waveform, the variation differences in both the chromaticity coordinate and color temperature were relatively small, implying that the negative sustain waveform also contributed to suppressing the temporal image sticking.

C. Monitoring of IR Emission

Fig. 7 shows the infrared (IR: 828 nm) emissions during the initial sustain discharge by applying the positive and negative sustain waveforms to the sustain electrodes. As shown in Fig. 7, when applying the negative sustain waveform, the IR emission peak was higher, implying that the sustain discharge was produced stronger in the case of applying the negative sustain waveform.

Fig. 8 shows the changes in IR emissions in the discharge region with a full-white background measured at both before and after a 5-min sustain discharge when applying the positive and negative sustain waveforms to the sustain electrodes, respectively. As shown in Fig. 8(a) and (b), the IR emission waveforms did not change through the 5-min sustain discharge irrespective of the types of the sustain waveform, whereas the changes in the luminance and color temperature through the 5-min sustain discharge were strongly dependent on the types of the sustain waveforms, as shown in Figs. 4 and 6. This confirmed that the deterioration in the luminance and color temperature was induced only by the change in the visible conversion capability of the phosphor layers. However, with the negative sustain waveform, the luminance and color temperature were slightly decreased, even though the initial discharge intensity were higher, as shown in Fig. 7.



(a)

(b)

Fig. 8. Changes in IR emission waveforms during sustain discharge measured before and after 5-min sustain discharge in discharge region when applying (a) positive and (b) negative sustain waveforms to sustain electrodes.

D. Monitoring of Address Current

Fig. 9 shows the discharge currents flowing through the address electrode (i.e., address currents) during the initial sustain discharge on the test panel when applying the positive and negative sustain waveforms to the sustain electrodes. In Fig. 9, the address currents flowing through the address electrode had two polarities during the surface discharge [13]. The first half of the address discharge current waveform showed a negative polarity meaning the incident ions from the sustain discharge, whereas the last half showed a positive polarity meaning the incident electrons from the sustain discharge. As shown in Fig. 9, for the negative sustain waveform, the address discharge current due to the incident ions during the sustain discharge was much reduced compared to that for the positive sustain waveform. The reduction in the address discharge current due to the ions incident into the address electrode resulted in the decrease in the ion bombardment onto the phosphor layer during the sustain discharge.

IV. Analysis of Temporal Image Sticking Induced by Negative Sustain Waveform

It is very difficult to measure precisely the changes in the surface state of the phosphor layer induced as a result of a 5-min sustain discharge. Accordingly, the changes in the absorbed hydrate and PL intensity of the phosphor layers were measured after the sustain discharge was continually produced

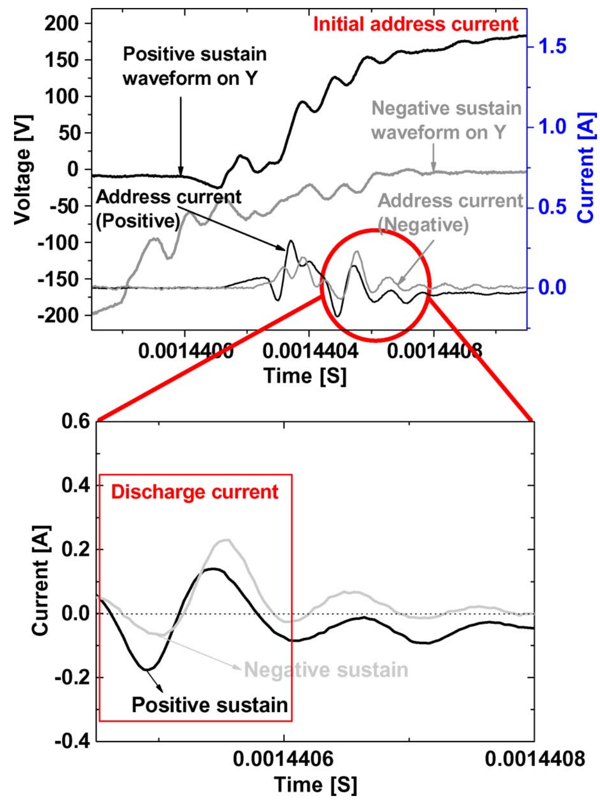


Fig. 9. Changes in address current waveforms during initial sustain discharge when applying positive and negative sustain waveforms to sustain electrodes.

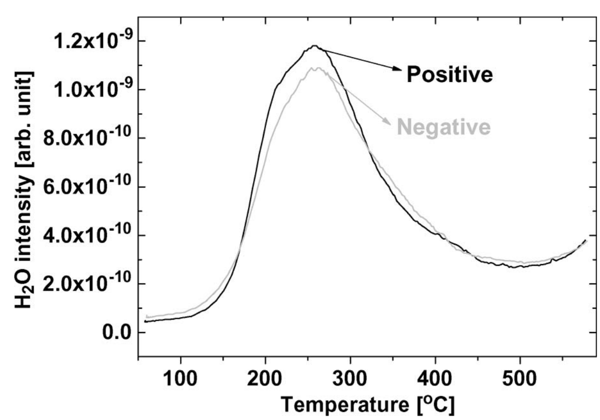


Fig. 10. Changes in profiles of H_2O intensity detected from phosphor layers before and after 60-min iterant sustain discharge when applying positive and negative sustain waveforms to sustain electrodes by using TDS analysis.

for about 60 min when using the two different sustain waveforms, such as the positive and negative sustain waveforms.

A. Monitoring of H_2O and Photoluminescence From Phosphor Layers

Fig. 10 shows the changes in the hydrate intensity, such as H_2O, on the phosphor layer of the test panel in the discharge region including the nondischarge region, when using the two different sustain waveforms. The H_2O intensity in Fig. 10 was obtained by measuring the outgassing intensity when heating the phosphor layer in the rear panel using the TDS analysis. As shown in Fig. 10, with the positive sustain waveform, the H_2O

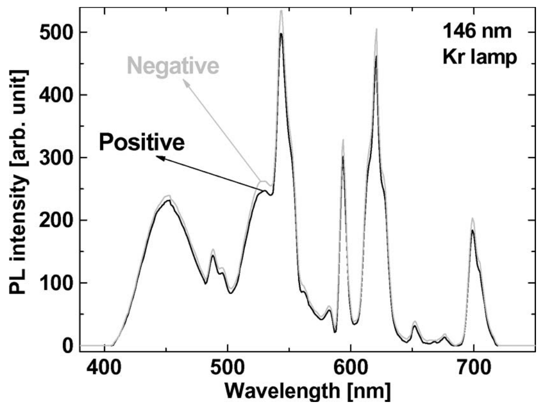


Fig. 11. Changes in photo intensity (146 nm using Kr lamp) detected from phosphor layers before and after 60-min iterant sustain discharge when applying positive and negative sustain waveforms to sustain electrodes by using PL analysis.

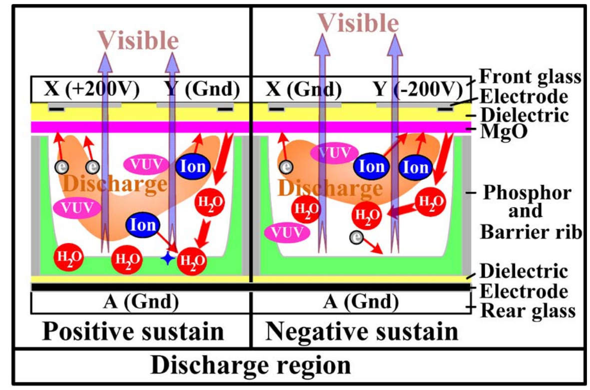


Fig. 12. Schematic-mechanism model describing temporal image sticking phenomenon when applying positive and negative sustain waveforms to sustain electrodes.

intensity on the phosphor layer was higher, implying that the absorption of the hydrate on the phosphor layer was made in the case of applying the positive sustain waveform. However, with the negative sustain waveform, the H_2O intensity was observed to be almost the same as that for the nondischarge case, implying that the additional absorption of the hydrate on the phosphor layer during the strong discharge was not made in the case of applying the negative sustain waveform. The measurement result of Fig. 10 postulates that reducing the ion bombardment of the phosphor layer can suppress the absorption of the hydrate on the phosphor layer.

Fig. 11 shows the profiles of the PL intensity (visible rays, 380–780 nm) emitted from the phosphor layers when using vacuum ultraviolet (VUV) with a wavelength of 146 nm from a Kr lamp to irradiate the degraded and nondegraded regions after a 60-min plasma discharge when applying the positive and negative sustain waveforms during the sustain discharge. As shown in Fig. 11, with the positive sustain waveform, the PL intensity emitted from the phosphor layer was lower, implying that the visible conversion capability from VUV by the phosphor layer was reduced in the case of applying the positive sustain waveform. However, with the negative sustain waveform, the PL intensity emitted from the phosphor layer was observed to be almost the same as that for the nondischarge case.

B. Schematic-Mechanism Model for Describing Temporal Image Sticking Phenomenon Induced by Negative Sustain Waveform

Based on the experimental results of the TDS and PL analyses, a schematic model describing the effects of the positive and negative sustain waveforms on the temporal image sticking is given in Fig. 12. When applying the negative sustain waveform, the temporal image sticking characteristics were improved, mainly due to less obstruction of the visible conversion as a result of less absorption of the H_2O on the phosphor layers [14]–[16]. When applying the negative sustain waveform, the lesser absorption of the H_2O on the phosphor layer was presumably due to more decrease in the hydrate with the phosphor layer by suppressing the ion bombardment of the phosphor layer during the sustain discharge produced by the negative sustain waveform. Therefore, it is expected that these experimental results will help to solve the temporal image sticking or image retention problems in the current PDP-TVs.

V. Conclusion

The effects of the types of sustain waveform such as the positive and negative sustain waveforms on the temporal image sticking were investigated and compared in a 6-in test panel with a Ne-Xe (10%) gas mixture at 200 kHz. Our experiment data on the differences in luminance, chromaticity coordinate, color temperature, IR emission, address current, hydrate, and PL showed that the negative sustain waveform was more effective in suppressing temporal image sticking than the positive sustain waveform. By blocking the ion bombardment of the phosphor layer in case of adopting the negative sustain waveform, the absorption of the H_2O onto the phosphor layer was effectively minimized, thereby resulting in suppressing the reduction of the luminance. As a result, the negative sustain waveform is confirmed to be a very effective sustain pulse for reducing temporal image sticking. Thus, it is expected that the negative sustain waveform will help to reduce the problem of temporal image sticking in ac PDP-TVs.

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