Investigation of Wall and Space Charges Decay Using Pulse Technique in AC Plasma Display Panel

Kyung Cheol Choi, *Member, IEEE*, Bhum Joon Kim, and Bhum Jae Shin, *Member, IEEE*

***Abstract*—Using simple pulse technique, two kinds of cases in alternating current (ac) plasma display panel were investigated. One is the relationship between the wall charge decay and the discharge aging time. The other is the relationship between space charge decay and the application of pulse to the address electrode during sustain period. For the former case, the minimum sustain voltage depended on the priming particles within a short time range (100 μs) of afterglow, then suddenly increased as the afterglow time increased. With a long time range (600 μs) of afterglow, the minimum sustain voltage depended on the state of the wall charges and gradually increased as the afterglow time increased. From these results, a time scale for the wall charge decay was obtained as a function of the discharge aging time. For latter case, the space charge decay time was 5 μs when there are no pulses applied to the address electrode. The space charge decay time was about 4 μs due to the application of pulses to the address electrode.**

***Index Terms*—Discharge aging, plasma display panel, pulse technique, space charge, wall charge.**

I. INTRODUCTION

WITH the spread of digital television, plasma display panels (PDPs) have become the most popular large-area and flat information displays. Since the late 1990s, many companies have been commercializing PDPs based on their various advantages, including their large screen size, thin dimensions, and excellent picture quality. Plus, due to recent innovations in technology, the image quality and performance of alternating current PDPs (ac PDPs) are compatible with those of a cathode ray tube (CRT) or thin film transistor liquid crystal display (TFT-LCD). Nonetheless, many of the phenomena related to the pixels in plasma display panels are still unknown, and one of the most important current topics is understanding the discharge characteristics of PDPs with regards to improving the luminous efficiency, image quality, and reliability. In this context, understanding the behavior of wall and space charges is a very important issue [1], [2], as they play a key role in generating the plasma and displaying an image in a PDP. Yet, the behavior of wall and space charges is not easy to understand, especially those connected to an MgO surface [3], [4]. Basically, the electrodes of an ac PDP are covered by a dielectric layer and then coated with a protective layer, usually a MgO thin film 500–800 nm thick, which plays an important role in igniting and sustaining the discharges in an ac PDP. During gas discharges, the space charges produced in a pixel turn to be wall charges on the MgO surface. Also, secondary electrons are produced from the MgO surface due to ion bombardment. As such, these wall charges and secondary electrons have a significant influence on the discharge characteristics, such as the firing and sustain voltage, luminance, efficiency, and reliability. In particular, the surface state of the MgO film is related to the discharge characteristics of an ac PDP [5], plus the secondary electron emission coefficient has been used as a parameter to investigate the relationship between the protecting layer and the discharge characteristics [6]. The wall charges of a pixel in an ac PDP are also related to the surface state of the MgO film and definitely influence the discharge characteristics, display image quality, and reliability. Accordingly, the current study investigated the wall charge state of an ac PDP during the discharge aging process, an important process involved in manufacturing PDPs that stabilizes the display characteristics related to MgO [7]–[10]. Discharge aging studies have already been undertaken to understand the characteristics of the discharge voltage, discharge currents, gas pressure, and variable driving conditions [8]. The condition of the wall charges varies according to the surface state of the MgO film, which is changed by the discharge aging process [10]. From the point of view of space charges, they are related to the luminance, the luminous efficacy, and the operation voltage in ac PDP. The space charges generated in subpixel turn to be wall charges within several microseconds. If we can control the space charge decay time, we can control also the display characteristics such as luminance, luminous efficacy, and operation voltage. Before that, the time scale related the space charge decay should be measured under the real driving conditions. Therefore, the current study examined the wall and the space charge decay time using the simple pulse technique proposed in the previous report [11]. In this work, we tried to investigate two cases in ac PDP. One is the relationship between the wall charge decay time and the aging time. The other is the relationship between space charge decay and the application of pulse to the address electrode during sustain period. Here, we suggest the methodology of analysis of the characteristics of the wall charge during discharge aging process and the space charge during sustain period in ac PDP.

II. PREPARATION OF AC PLASMA DISPLAY TEST PANEL

Fig. 1 shows a schematic diagram of the 2.54-in test plasma display panel used in the current study. This kind of reflection type three-electrode surface-discharge structure is most widely used for an ac PDP. The specific feature of the structure shown in Fig. 1 is a stripe barrier rib with an aspect ratio (defined as the vertical pixel pitch relative to the horizontal pixel pitch

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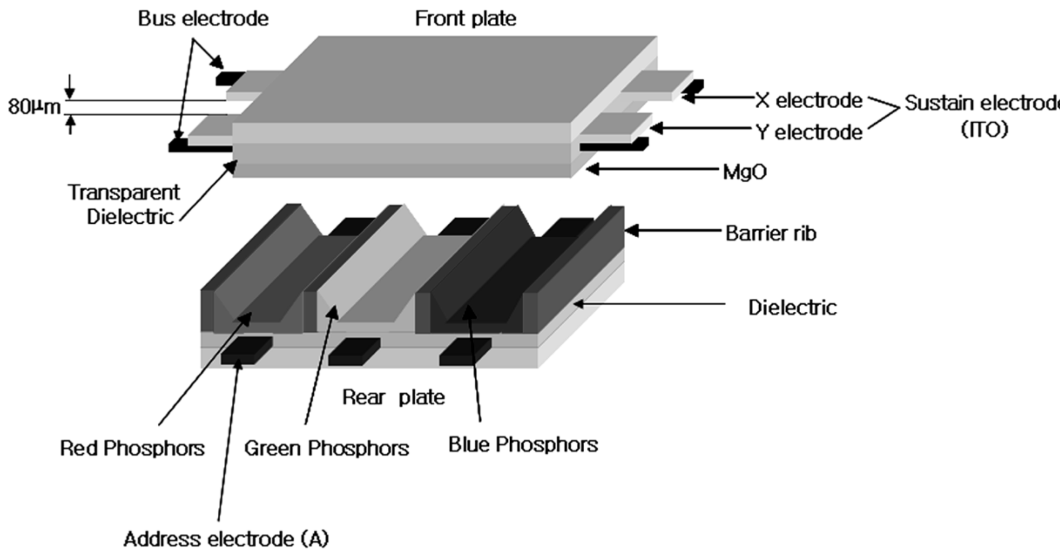

Fig. 1. Schematic diagram of cell structure of ac plasma display test panel.

of a subpixel) of 1–3, and the dimensions of a subpixel are 0.36 mm × 1.08 mm. The X and Y electrodes, used to scan and sustain the discharges, are formed on the front plate and covered with a transparent dielectric layer and protecting layer (MgO). Here, the X and Y electrodes, which are also transparent and made of indium tin oxide (ITO), include a bus electrode to reduce the electrical resistivity when the discharge current flows through the ITO. Meanwhile, the address electrodes are formed on the rear plate and covered by a dielectric layer and phosphors. As such, the barrier ribs create a space between the front and rear plates for discharges. The height of the barrier rib is 0.12 mm and the nonconducting spacing between the X and Y electrodes is 80 μm. An Ne+He (30%)+Xe (4%) gas-mixture was used as the discharge gas and the total pressure was 400 torr. All test panel used in this work was subjected to annealing and evacuation process during 5 h under 350 °C. When pulses were applied to the X and Y electrodes, discharges occurred and space charges were generated in the subpixels. Some of the space charges remained on the surface of the protecting layer and turned into wall charges during the afterglow. The pulse of 220 V and 25 KHz were applied to the sustain electrodes during the discharge aging process.

III. Results and Discussion

A. Case Study 1

Fig. 2 shows the pulse waveforms applied to the X and Y electrodes and used to measure the wall charge decay time. The width of the pulse was fixed as 4 μs and the whole driving frequency was changed as the $\Delta\mathrm{t}1$ was varied. The time interval between the X and Y sustain pulse was 1 μs, plus $\Delta\mathrm{t}1$ denotes the time of the afterglow, which ranged from 1 μs to 1 ms in the current experiment.

To investigate the characteristics of the wall charge decay time relative to the conditions of the discharge aging process, the minimum sustain voltage(V_{smin}) was measured as a function of $\Delta\mathrm{t}1$ according to various discharge aging times. Fig. 3 shows the minimum sustain voltage as a function of $\Delta\mathrm{t}1$ in accordance with the discharge aging time. Here, the minimum sustain voltage was defined as the discharge-off voltage. When pulses are applied to the X and Y electrodes and their voltage is above the firing voltage, space charges, excited particles, and

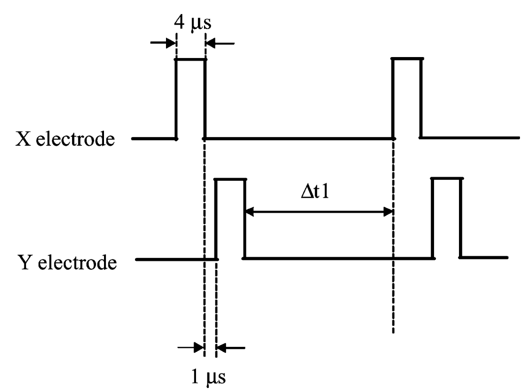

Fig. 2. Pulse waveforms applied to X and Y electrodes and used to measure the wall charge decay time.

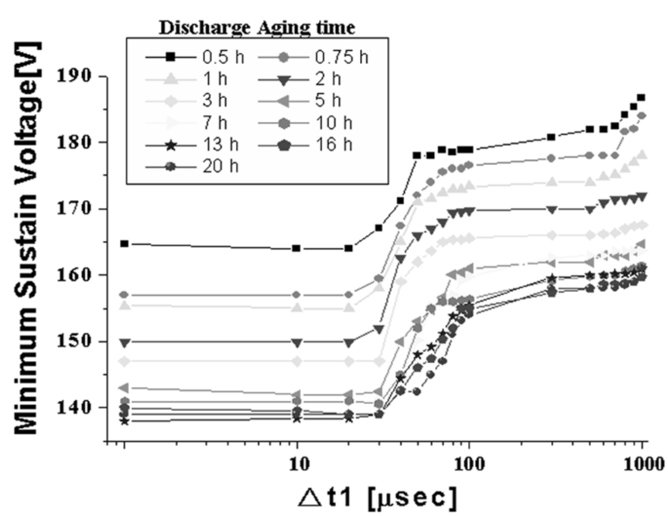

Fig. 3. Minimum sustain voltage as a function of $\Delta\mathrm{t}1$ in accordance with the discharge aging time.

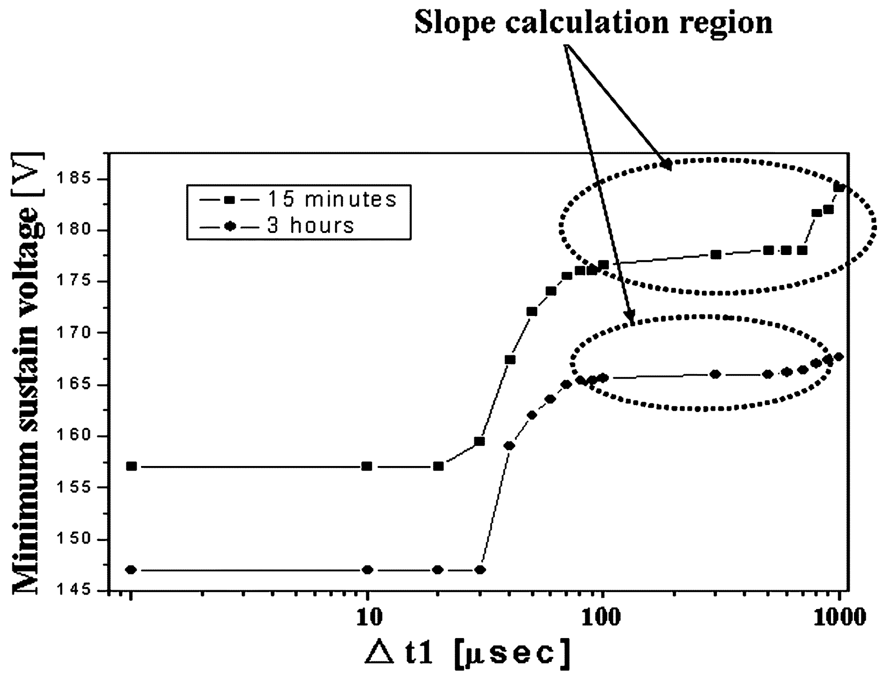

Fig. 4. Minimum sustain voltage as function of $\Delta t1$ in accordance with 15 min and 3 h aging time.

meta-stable particles are generated in the pixels. Then, during the afterglow($\Delta t1$), the space charges and meta-stable particles decay, plus some of the space charges become wall charges on the protecting layer. Generally, the lifetime of meta-stable particles is longer than that of charged particles, while the lifetime of wall charges is much longer compared to that of meta-stable particles. Thus, it is the meta-stable particles and wall charges that usually have an affect on maintaining the discharges. The minimum sustain voltage decreased with an increase in the discharge aging time up to 13 h. As previously mentioned, the main purpose of the discharge aging process is to stabilize the discharge during sustain, address, and reset periods. Immediately after a panel is prepared, the discharges in a pixel of an ac PDP are unstable due to the morphology and contaminated surface state of the protecting layer [5], [11]. Thus, during the discharge aging process, the energetic ions generated in the pixels bombard the protecting layer, which changes its surface state. As a result, the minimum sustain voltage decreases. In the current study, after 13 h of discharge aging time, the minimum sustain voltage did not increase any more, indicating the completion of the change in the surface state of the protecting layer as a result of the discharge aging process. As shown in Fig. 4, the minimum sustain voltage increased drastically when $\Delta t1$ was 20–100 μs, which was due to the reduction of metastable particles during the afterglow [11]. After 100 μs, the minimum sustain voltage slowly increased depending on the state of the wall charges, then when $\Delta t1$ was between 100 and 600 μs, the variation in the minimum sustain voltage exhibited a similar tendency for all the discharge aging times. However, after 600 μs, the variation in the minimum sustain voltage differed somewhat according to the discharge aging time. Within a discharge aging time of 1 h, the panel showed a large variation in the minimum sustain voltage, probably due a large loss of wall charges resulting from an insufficient discharge aging time.

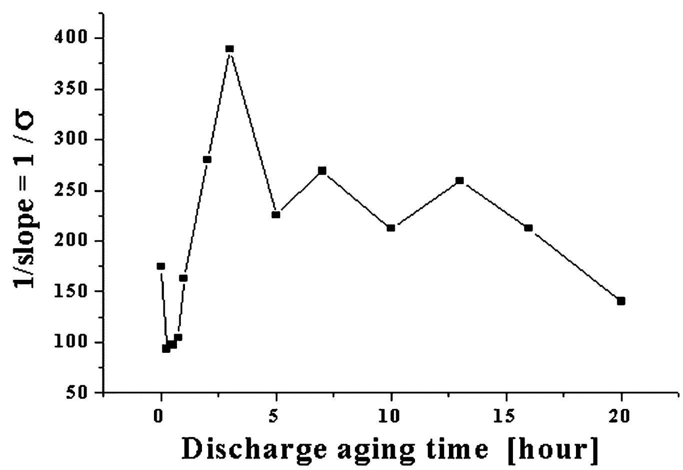

Fig. 5. $1/\sigma$ as function of discharge aging time.

For a clear representation of the variation in the minimum sustain voltage after a $\Delta t1$ of 100 μs, Fig. 4 shows the minimum sustain voltage as a function of $\Delta t1$ according to two different discharge aging times. In the case of a 15-min discharge aging time, the minimum sustain voltage increased by 10 V from 100 μs to 1 ms. However, in the case of a 3-h discharge aging time, the minimum sustain voltage only increased by 2 V during the same time. The increase in the minimum sustain voltage from 100 μs to 1 ms was due to the decay of the wall charges, which in turn depended on the surface state of the MgO film. It is well known that the surface properties of the MgO film are changed by the ion bombardment during a discharge [7]. Thus, the increased wall charge loss resulted from the surface state of the MgO film due to an insufficient discharge aging time. It was found that an appropriate surface state for reducing the wall charge loss could be obtained with a sufficient discharge time. The relationship between the decay of the wall

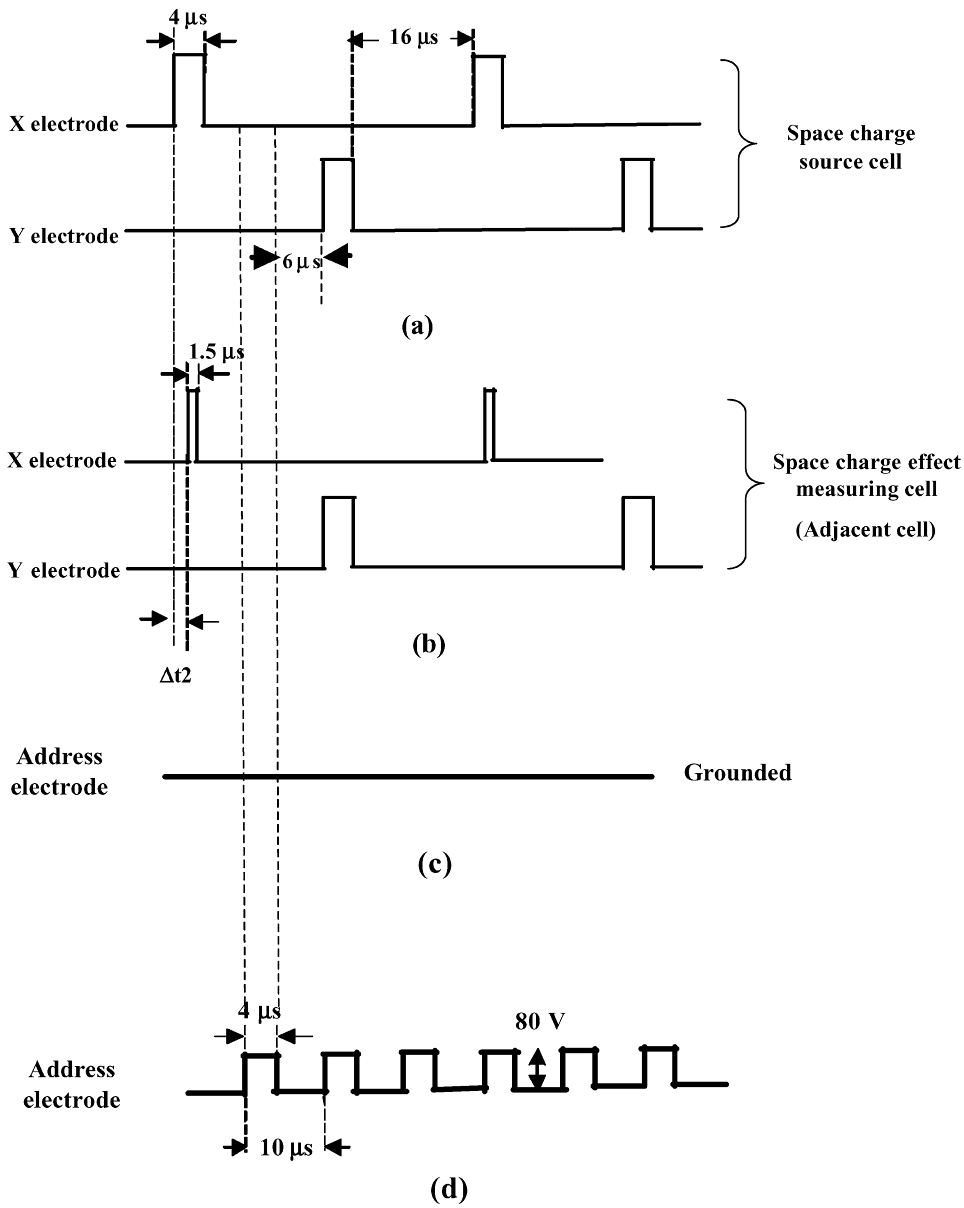

Fig. 6. Pulse waveforms applied to X, Y, and address electrodes and used to measure the space charge decay time. (a) Pulses waveforms applied to the source cell. (b) Pulses waveforms applied to the space charge effect measuring cell. (c) Address electrode is grounded. (d) Pulse waveforms applied to address electrode during sustain period.

charges on the protecting layer and the discharge aging time was also determined.

The average slope after saturation of curve in Figs. 3 and 4, was defined as σ and the actual wall charge decay time was related to $1/\sigma$ [11]. There are two possibilities to explain the increase of minimum sustain voltage after 100 μs. One possibility is due to the decay of exo-emission priming particles [12]. Shiga, *et al.* reported that the exoelectron emission continues after the completed decay of meta-stable particles in ac plasma display panel [12]. The other possibility is due to the lateral surface charge leakage. Somerville and Vidaud mentioned the surface spreading charge on the insulator [13]. Nikonv *et al.* also showed the surface charge spreading and migration over a dielectric electrode with time as parameter [14]. In this work, the time scale of wall charge decay is related to the wall charge spreading and migration on the MgO surface. The shade area of Fig. 4 was for the slope calculation region. As such, a lower σ means a longer wall charge decay time. Fig. 5 shows the inverse of σ as a function of the discharge aging time, where $1/\sigma$ decreased within a 15-min discharge aging time, and increased thereafter. At the beginning of the discharge aging process, there was an unstable time region because the surface of the MgO film was very rough. Then, as the discharge aging process continued, the MgO surface became smoothened and $1/\sigma$ started to increase. An increase in $1/\sigma$ indicates an increase in the time scale in relation to the wall charge loss. As shown in Fig. 5, the maximum value for $1/\sigma$ was with a 3-h discharge aging time, indicating that the surface state of the MgO film was unsuitable for wall charges to remain within a 3-h discharge aging time. Meanwhile, the time scale related to the wall charge decay decreased with an increase in the discharge aging time after a 3-h aging time, indicating that the surface state of the MgO film was

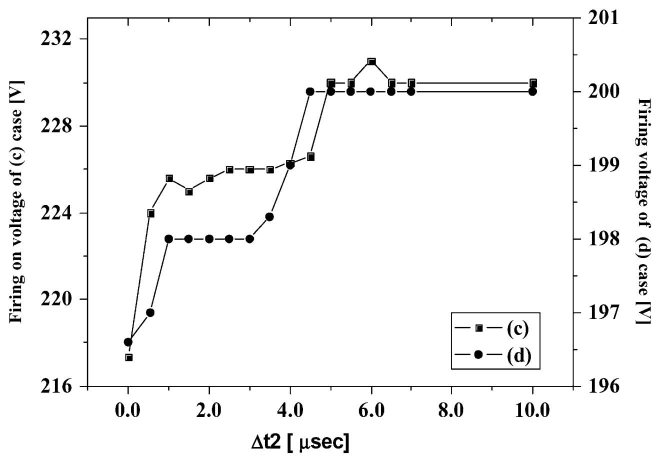

Fig. 7. Firing voltage of the space charge effect measuring cell as a function of $\Delta t2$ in accordance of (c) and (d) cases of Fig. 6.

stabilized for wall charges due to the ion bombardment during the discharge aging time.

B. Case Study 2

In this case study, we measured the space charge decay time during sustain period when the address was grounded and the periodic pulse was applied to the address electrode, respectively. We already reported the improved luminance and the luminous efficacy using the application of pulses to the address electrode during sustain period [15], [16]. However, we do not know what are exactly happened to the micro-plasma in the subpixel when the pulses are applied to the address electrode or to other electrode during sustain period. This current work just shows the methodology to analysis the space charge under the real operation condition. Fig. 6 shows the waveforms applied to each electrode and display cells during sustain period. Fig. 6(a) shows the waveforms applied to X and Y electrode in space charge source cell which produces the charged particles and influence on the adjacent cell [11]. Fig. 6(b) shows the pulse waveforms applied to X and Y electrode in the space charge effect measuring cell which is the adjacent cell of space charge source cell and influenced by the space charge flowing from the space charge source cell. Fig. 6(c) shows the address is grounded during sustain period. Fig. 6(d) shows the pulse waveform applied to the address electrode during sustain period. The frequency and the width of the pulses were 100 KHz and 4 μs, respectively. When the pulses of Fig. 6(a) were applied to X and Y electrode of one cell, the space charges were generated and spread to adjacent cell. Before the decay of the space charge, the adjacent cell was influenced and its firing voltage was reduced. After the space charges were completely decayed, the adjacent cell is not influenced any more. The pulse waveforms as shown in Fig. 6(b) are applied to the adjacent cell. Then, the time interval, $\Delta t2$, was varied from 0 to 10 μs. If the space charges produced at the space charge source cell are still alive, the firing voltage of the adjacent cell can be reduced.

Fig. 7 shows the firing voltage of the space charge effect measuring cell as a function of $\Delta t2$ in accordance of the grounded address electrode and the application of periodic pulses to address electrode. At the beginning point, the pulse applied to space charge effect measuring cell could attract the maximum number of space charges produced in space charge source cell. As $\Delta t2$ increased, the number of space charge that the pulse could attract decreased because the space charges were being decayed. Finally, the firing voltage did not increased any more after the space charges were completely decayed. The time of the space charge decay was about 5 μs when the address electrode was grounded. The space charge decay time was about 4 μs when the periodic pulses were applied to the address electrode as shown in Fig. 6(d). From the result, it is found that the application of the periodic pulse to address electrode during sustain period can reduce the space charge decaying time. This phenomenon can be applied when perturbation pulses from any electrode were given to the micro-plasma in cell of plasma display panel.

IV. Conclusion

The current study investigated two cases of plasma display panel. One is related to the wall charge decay time during discharge aging. The other is something about the space charge decay time when the periodic pulses are applied to the address electrode. For former case, the variation in the minimum sustain voltage was governed by the priming particles within 100 μs of afterglow time. However, with a long time scale (after 600 μs), the minimum sustain voltage became dependent on the state of the wall charges. Therefore, based on the characteristics of the minimum sustain voltage, a time scale related to the wall charge decay was obtained as a function of the discharge aging time. The time scale related to the wall charge decay increased within a 3-h discharge aging time and decreased thereafter. It was also found that an insufficient discharge aging time resulted in a faster wall charge decay on the surface of the MgO film. Although the discharge aging time is mainly determined by the characteristics of the discharge voltage, currents, and stability of the luminance, the current work found that the wall charge decay time was also a possible factor for determining the discharge aging time. For latter case, the firing voltage of space charge effect cell increased as the $\Delta t2$ increased until 5 μs for the case of the grounded address electrode and 4 μs for the case of the application of the periodic pulses to address electrode, respectively. It is also found that the space charge decay time can be reduced by the pulse applied to the address electrode during sustain period. From the results, this simple pulse technique can be used to find out the phenomena related to the wall and the space charge in ac plasma display panel under real driving conditions.

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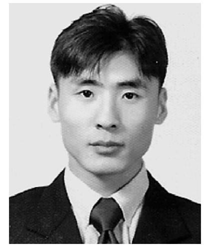

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