Case Studies on Temperature-Dependent Characteristics in AC PDPs

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***Abstract*—The temperature-dependent characteristics of ac plasma display panels (PDPs) are investigated, based on various case studies using a conventional driving scheme with reset pulses. Though the main factor of the thermal effects is caused by strong sustain discharges, it is not only caused by the panel characteristics, but also by the temperature-dependent characteristics of the driving system. One important thermal effect is a decreased breakdown voltage due to an increase in the panel temperature. Therefore, these results may be helpful in solving image-sticking and temperature-related phenomena.**

***Index Terms*—Image sticking, light emission, reset discharge, sustain discharge, thermal effects.**

I. INTRODUCTION

PLASMA display panels (PDPs) have been rapidly commercialized for high-definition television due to their large size, slim structure, and self-emissive color image quality. However, several critical issues remain regarding their low-luminous efficiency and poor image quality [1]–[3]. One of the great advances related to PDPs is the ramp reset driving scheme invented by Weber, which not only reduces the light emission of the reset discharges, but also improves the operation stability compared to previous self-erasing driving schemes [4], [5]. Although various studies have attempted to elucidate the operation mechanism of this driving scheme, it is still not fully understood at this time due to the numerous parameters that affect the operation [6]–[10].

Since the reset period is to play the most important role in the driving scheme, the characteristics of the reset discharges are investigated first to understand the operation mechanism. However, as the measurable quantities in a reset period, (including the light emissions, luminance, and currents) are very small and sensitive to the operation conditions, reasonable measurement conditions should be established. The measurement variables, especially in a reset period, were strongly dependent on the initial conditions of a panel and a driving system, and were changed as increasing an operating time before they were stabilized. It is obvious that the operating time is related to change in the temperature of a panel and a driving system. Thus, this paper briefly describes some of the basic characteristics related to temperature effects.

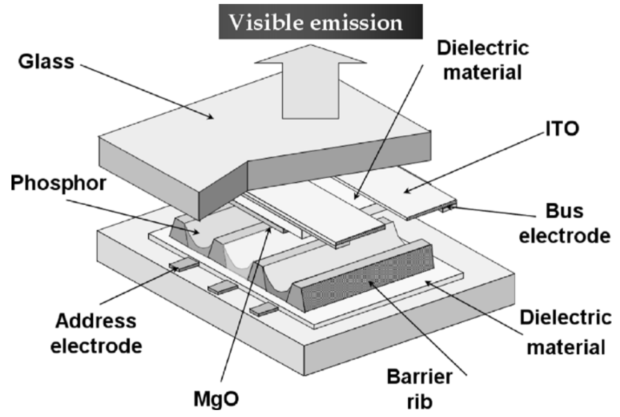

Fig. 1. Schematic diagram of conventional reflective three-electrode surface discharge type of ac PDPs.

II. BACKGROUND

A. Experimental Conditions

1) Test Panel Specifications: The cell structure of the test panel is a conventional reflective 3-electrode surface discharge type of ac PDP, as shown in Fig. 1, where the transparent conductive electrodes with a bus electrode, normally called the common electrode (X) and scan electrode (Y), are responsible for the sustain discharge, while the address electrodes (A) are responsible for the address discharge [11]. The pixel pitch is 0.81 mm × 0.81 mm, as designed for a 50" WXGA(1386 × 768) display format.

2) Test Driving Scheme: The test driving scheme is designed based on a conventional ADS with ramp reset pulses, as shown in Fig. 2. The total period is 1 μs, which was selected for measurement convenience and certain other considerations. The total number of sustain pulses is 12, which is rather small to minimize the thermal effect due to strong discharges. However, since the discharges during the sustain period are stabilized within a few sustain pluses under proper operation conditions, the final wall voltage resulting from the sustain discharge is definitely stabilized. Both the address pulse width and sustain pulse width are set to 5 s to guarantee a stable operation, plus the width of the first sustain pulse is set to 20 s for the same reason.

3) Measurement Equipment: This study uses four major measurement variables: the luminance, which is measured using

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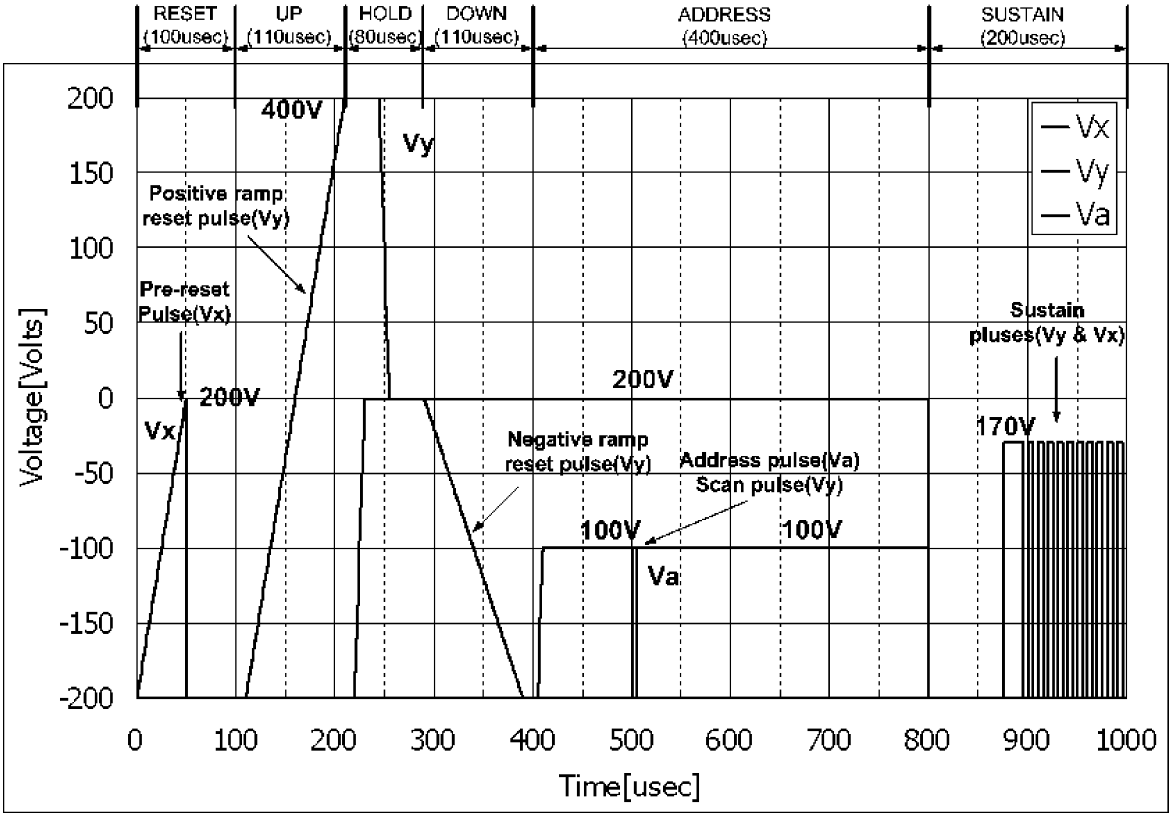


Fig. 2. Test driving scheme.

a Color analyzer (Minolta CA-100plus), the light emission, which is measured using a photosensor amplifier (Hamamatsu C6386), the current, which is measured using a digital multimeter (HP 34 401A), and the temperature, which is measured using a conventional thermometer. Although the spectral range of the photosensor amplifier ranges from 400 nm to 1200 nm, its maximum photo sensitivity is from 700 nm to 900 nm; therefore, the light emission in this study can be considered as an IR emission. As time-dependent characteristics are mainly caused by the effect of temperature, temperature would seem to be a more reasonable indicator than the operating time. However, for convenience, this study uses the operating time instead of temperature, yet temperature data are also presented to provide a better understanding.

B. Temperature-Dependent Variables in AC PDPs

There are many time-dependent variables that are dependent on the temperature, yet these variables can be divided into two basic categories according to the following descriptions.

1) Driving System and Circuit Elements: A driving system includes a lot of circuit elements with characteristics that are dependent on the temperature. Although there are numerous types of circuit element and varied configurations, this description focuses on the driving system used in the present study, an AWG (Arbitrary Waveform generator) driving system, which is a commercial product that consists of two main parts (Logic circuits with a high voltage OP amp and Switching circuits with a high voltage FET).

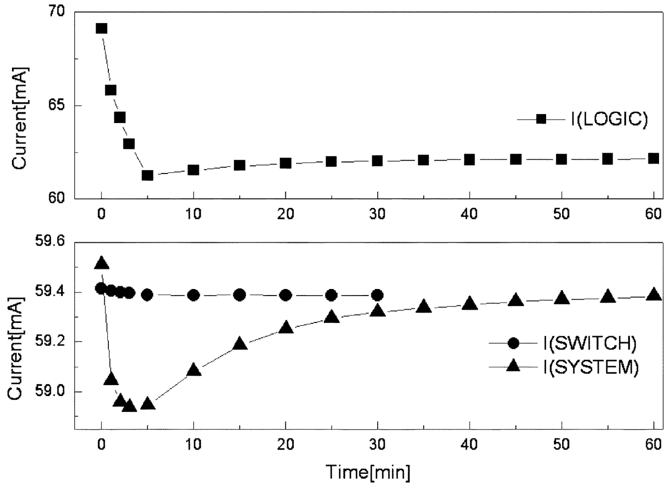


Fig. 3. Time varying current as a function of operating time. (without panel connection).

Fig. 3 shows the time variations in the currents as a function of the operating time, where $\mathrm{I(Logic)}$ means the current for the logic circuits, $\mathrm{I(Switch)}$ means the total current for the logic circuits and switching circuits, measured after the logic circuits are stabilized when using the test driving scheme, as shown in Fig. 2, and $\mathrm{I(System)}$ means the total current for the logic circuits and switching circuits that are turned on at the same time. As shown in Fig. 3, the current variations are mainly determined by the logic circuits with a high-voltage OP amp, and the saturation time for the driving system is around 50 min. After the logic circuits are stabilized, the saturation time for the switch circuits is around 10 min. Even though these results will inevitably differ according to the driving system, the driving system should still

TABLE I
TEMPERATURE-DEPENDENT VARIABLES AND POSSIBLE FACTORS IN PANEL

Temperature -dependent variables	Possible Factors
MgO layer	secondary electron emission coefficients, etc
phosphor layer	secondary electron emission coefficients, quantum efficiency, etc
gases	kinetic energy of gases, etc
dielectric layer	dielectric constant, etc
bus electrode	conductivity, etc

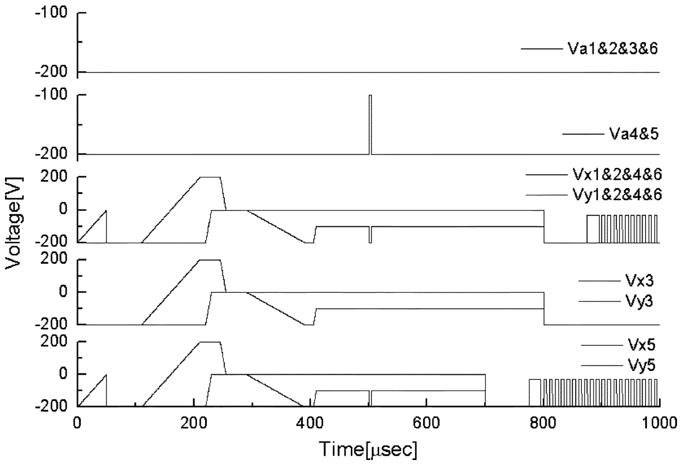


Fig. 4. Driving schemes used for each case study.

be considered as a factor affecting the temperature dependent characteristics. Therefore, based on the above results, all further experiments are carried out after the driving system has been stabilized.

2) Panel Elements: A basic list of the many variables that are temperature dependent is included in Table I. However, since the thermal effects of these factors are unknown, the results of various case studies are presented along with some discussion.

III. EXPERIMENTAL RESULTS AND DISCUSSION

To investigate the effect of a particular factor, all the other conditions need to remain the same. Yet, this is very difficult or even impossible when driving a panel. For instance, if the pixels in a panel are turned on, currents flow into the circuit elements and pixels, thereby heating both the circuit elements and the panel. Therefore, there may be some coupling effects in the case studies.

Fig. 4 shows the driving conditions used for each case study, where the last number of the legend represents the number of the case study. As shown in Fig. 4, as regards Va (applied to the address electrode), there are two different conditions: address–on and address–off. The address–off condition means that only reset discharges occur during the reset period; therefore, this condition can be considered as a relatively low-temperature condition for the panel and circuits. Meanwhile, the address–on condition means the occurrence of both strong address discharges and sustain discharges; therefore, this condition can be considered as a relatively high-temperature condition for the panel and circuits. With regards to Vx (applied to the common electrode) and Vy (applied to the scan electrode), there are three different conditions: normal sustain pulse (12 pulses including pre-reset pulses), no sustain pulse (0 pulse), and large sustain pulse (22 pulses including prereset pulses). Therefore, the large sustain pulse condition can be considered as a high-temperature case, the no sustain pulse condition as a low-temperature case, and the normal sustain pulse condition as a medium-temperature case. The initial and saturation temperature data are listed in Table II.

TABLE II
INITIAL AND SATURATION TEMPERATURE FOR EACH CASE STUDY

Case study	Address condition	Sustain condition	Initial Temp (C)	Saturation Temp (C)
Case 1	OFF	Normal sustain	22	23.3
Case 2	OFF	Normal sustain	22	23.3
Case 3	OFF	No sustain	22	22.7
Case 4	ON	Normal sustain	22	30.9
Case 5	ON	Large sustain	22	38.4
Case 6	OFF	Normal sustain	38.4	24

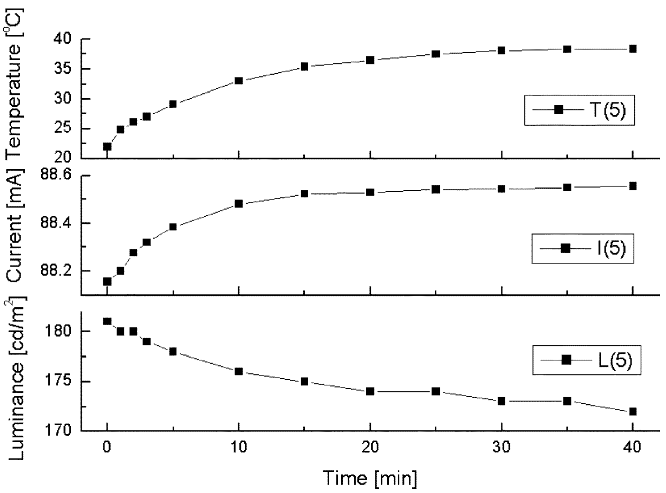


Fig. 5. Luminance, current, and panel temperature as a function of operating time (Case 5).

Fig. 5 shows the luminance, current, and panel temperature as a function of the operating time in the Case 5 experiment. As the operating time is increased, the current and temperature is increased while the luminance is decreased. Furthermore, the characteristics of the temperature and the current on the dependence of the operating time show the same tendency. The detailed discussion will be described in later section.

The major measurement variable in this study was the light emission waveforms during the reset period. Fig. 6 shows the light emission waveforms for Case 2 and Case 4 for the whole reset period, including the prereset period, to help clarify the subsequent figures. The notation $\mathrm{L(RE)00\ min\ 2}$ represents the light emission [L] from the reset discharge [(RE)] after 00 min in Case 2. However, since the outputs of the driving system were manually connected to the panel, this required time (around 15 s). Therefore, the actual time of 00 min was 15 s. As shown in Fig. 6, the light emission waveforms for Case 2 indicated an

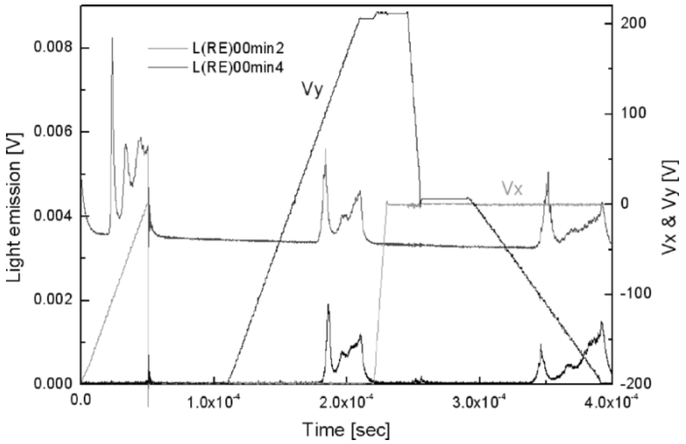


Fig. 6. Light emission waveforms for Case 2 and Case 4 during prereset period and reset period.

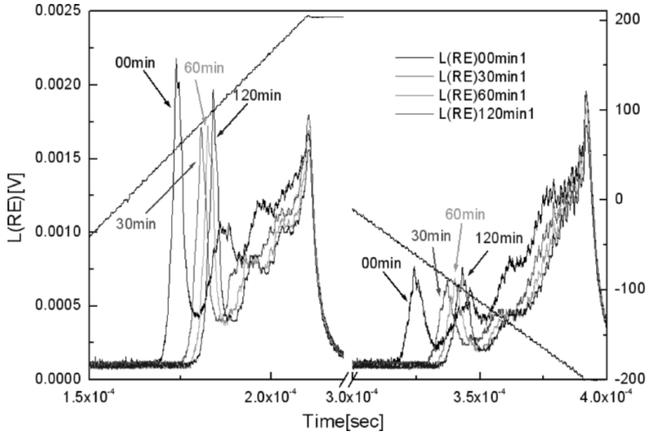


Fig. 7. Light emission for reset period as a function of operating time (Case1).

address–off condition, while those for Case 4 indicated an address–on condition. Although using the same axis scale is convenient for comparison, since the variations were so small, the time scale was changed for each case study for clearer presentation, yet the light emission scale remained the same.

A. Temperature Effects of Driving System

Since the variation of I(LOGIC) is initially rather large and unstable, as shown in Fig. 3(a) and (b), and involves a lot of circuit elements, where the effects are also dependent on the system configuration, all the experiments were carried out after the driving system had been stabilized.

1) Case 1 (After Stabilizing Logic Circuits): Fig. 7 shows the light emission waveforms during the positive ramp reset and negative ramp reset period as a function of the operating time. The discharge starting voltage of the reset discharges [hereafter, Vyx(RE)d] increased, which may have been due to either or both the panel (increasing the breakdown voltage of the panel) and the switching circuits (decreasing the outputs of the switching circuits). To verify the factors influencing these variations, the output voltage of the driving system was first measured as function of the operating time. However, the output voltage eventually did not change as a function of time, which is not shown in this paper, plus the temperature effect of the panel was also negligible in this situation, as described later. Therefore, the factors affecting this variation were likely related to the change in the impedance of the circuit elements, such as the Rds(ON) of the FETs, and panel elements, such as the conductivity of the bus electrodes, yet this requires further study.

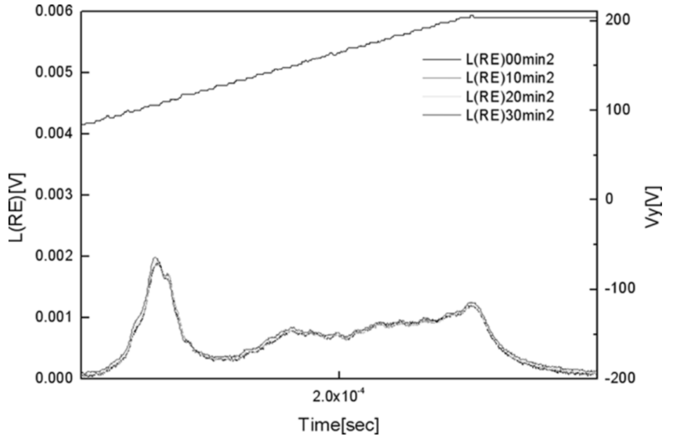


Fig. 8. Light emission waveforms for positive ramp reset period as a function of operating time (Case2).

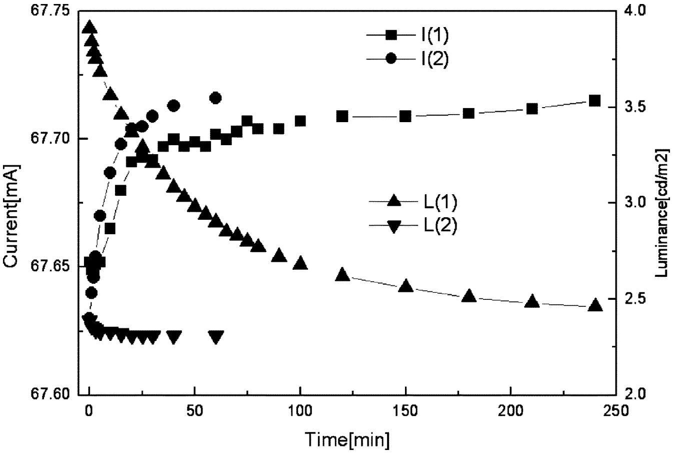


Fig. 9. Current and luminance as a function of operating time (Case 1 and Case 2).

2) Case 2 (After Stabilizing Driving System): As shown in Fig. 8, the light emission waveforms showed no variation as a function of the operating time. Therefore, the time-varying characteristics in Fig. 7 were probably caused by the temperature dependency of the switching circuits. As such, it would appear that the thermal effect due to weak reset discharges was basically negligible, thus the switching circuits were the major factor involved in the time-varying characteristics in Case 1.

Fig. 9 shows the current and luminance for Case 1 and Case 2 as a function of the operating time, where the current represents the total current, including both the driving system and the panel. For the results of Case 1, when increasing the operation time, the luminance decreased, while the current increased. One reason for the decreased luminance can be inferred from the light emission waveforms shown in Fig. 7. The operating time increased the Vyx(RE)d, thereby decreasing the light emission time. In addition, the intensity of the light emissions also decreased slightly with an increased operation time. Therefore, at least in this situation, the decreased luminance was mainly caused by the decreased intensity of the light emissions, rather than the phosphor characteristics, which will be described later. However, for the results of Case 2, when increasing the operation time, the luminance is very slightly decreased, while the current is increased more than that of Case 1. One of possible reasons for increased currents of Case 2 is the different initial stabilized currents. As shown in Fig. 3, the current was changed from 62.20 mA to 67.65 mA in the Case 1, while it was changed from 59.40 mA to 67.63 mA in the Case 2. Therefore, for the Case 2, the main factor for the current variation is the logic circuits of driving system, yet this requires further study. However, after the driving system was stabilized, the luminance and the current were the same for both cases.

In briefly summarized, for the Case 1 and Case 2 experiments which have no strong address and sustain discharges, the variations of the current and luminance on the dependence of the operating time is mainly related to the properties of the driving system, not that of the panel. Furthermore, from the results of the Case 2, it can be inferred that the weak reset discharges are not the factor which is related to the temperature-dependent characteristics.

B. Temperature Effects of Panel (Heated by Reactive Power due to Sustain Pulses)

Basically, there are two main factors that can increase the panel temperature: strong address and sustain discharges and reactive power heating due to the sustain pulses. The reactive power heating is caused by the displacement current, which is induced by the capacitance of the discharge cell when the sustain pulses are applied to the sustain electrodes. Therefore, the energy recovery circuits are essential for the commercial PDP products to reduce the reactive power loss. However, the AWG driving system does not have energy recovery circuits. This case study investigated the temperature effect of reactive power heating before investigating the temperature effect of strong discharges.

1) Case 3 (After Stabilizing Driving System): Since the sustain pulses are relatively small in the test driving scheme, the temperature effect due to the reactive power heating was assumed to be very small or negligible, as shown in Fig. 8. However, test driving scheme for Case 3 is designed for verification. In the test driving scheme for Case 3, the sustain pulses are removed to eliminate the reactive power heating, which is induced by the sustain pulses. Fig. 10 shows the difference in the light emission waveforms between Case 2 and Case 3, indicating that the effect of the reactive power heating was negligible under the test driving conditions.

C. Temperature Effects of Panel (Heated by Strong Discharges)

1) Case 4 (After Stabilizing Driving System): Fig. 11(a) and (b) show the light emission waveforms as a function of the operating time during the positive ramp reset and prereset period, respectively. As shown in Fig. 11(a), $\mathrm{Vyx(RE)d}$ decreased briefly and the saturation time was around 20 min. The difference in $\mathrm{Vyx(RE)d}$ between 0 min and 20 min was roughly around 8 V, which is a rather large value. However, the pure effect should be halved, as the wall voltage after the prereset pulse was similarly affected, as shown in Fig. 11(b).

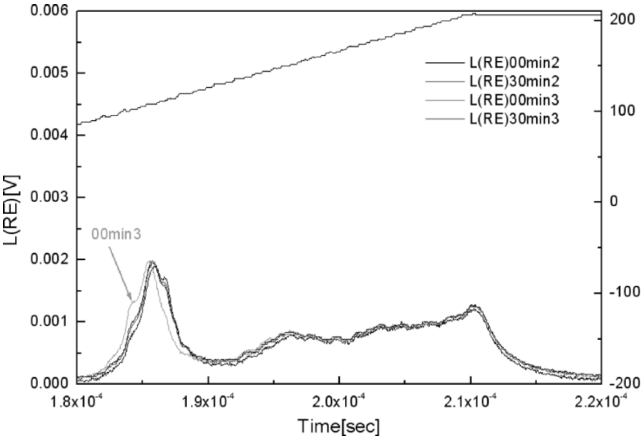
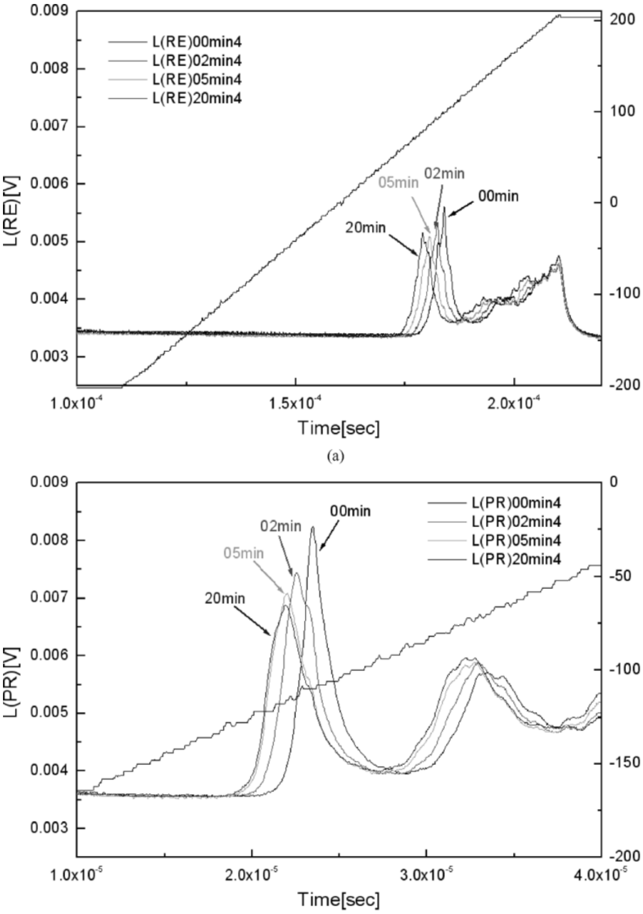


Fig. 10. Light emission waveforms for positive ramp reset period as a function of operating time (Case2 and Case 3).



(a)

(b)

Fig. 11. (a). Light emission waveforms for positive ramp reset period as a function of operating time (Case 4) and (b) light emission waveforms for prereset period as a function of operating time (Case 4).

2) Case 5 (After Stabilizing Driving System): From the results of Case 4, it can be inferred that panel heating due to strong discharges decreased the breakdown voltage of pixel. Thus, to further investigate the temperature effect of strong discharges, the driving scheme was changed to include more sustain pulses. Fig. 12 compares the light emission waveforms for Case 4 and Case 5. The initial variation between Case 4 and Case 5 was

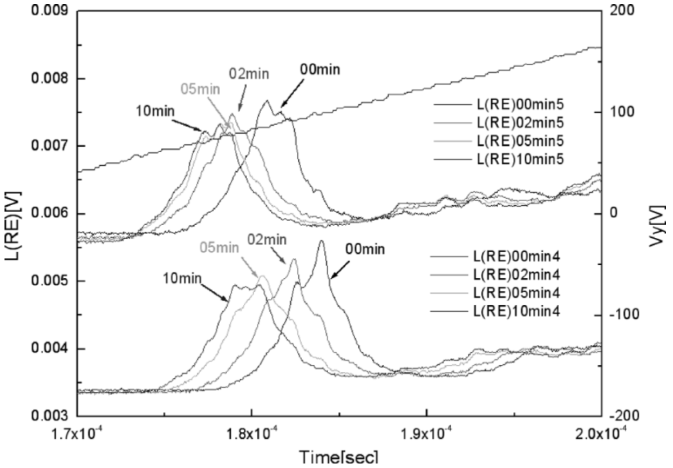


Fig. 12. Light emission waveforms for positive ramp reset period as a function of operating time (Case 4 and Case 5).

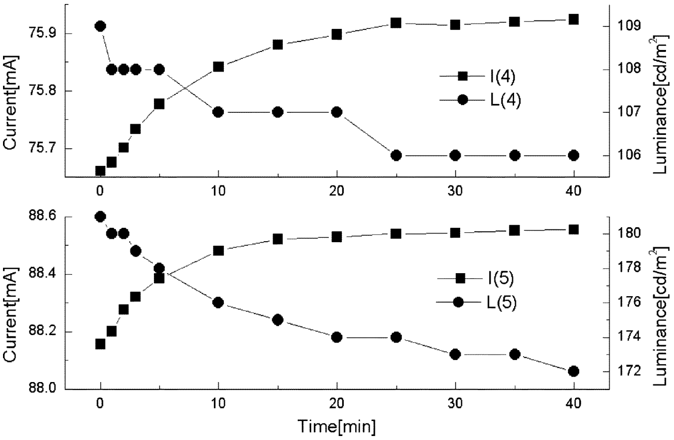


Fig. 13. Current and luminance as a function of operating time (Case 4 and Case 5).

mainly caused by the manual connecting time, as described previously, and possibly by a different operating current level for the driving system.

As shown in Fig. 12, $\mathrm{Vyx(RE)d}$ for Case 5 was slightly lower than that for Case 4, meaning that the breakdown voltage was also lower. Thus, even though these two cases operated under different current levels, the higher temperature of the switching circuits made $\mathrm{Vyx(RE)d}$ increase, as described previously. As such, it would appear that increasing the panel temperature decreased the breakdown voltage.

Fig. 13 shows the luminance and current as a function of the operating time for Case 4 and Case 5, where the luminance decreased, while the current increased with an increasing operating time. Therefore, the light emission waveform of the first sustain pulse was measured to verify the factors involved in the decreased luminance. As shown in Fig. 14, the light emission intensities increased with an increased operation time. Clearly, an exact analysis involving lengthy descriptions is required to consider the full operation, including the address period. However, since the intensity of the sustain discharge increased with an increased temperature, this may also explain the lower breakdown voltage. As such, it was concluded that the decreased luminance was not caused by a decrease in the intensity of the sustain discharges but rather by the thermal characteristics of the phosphor layer.

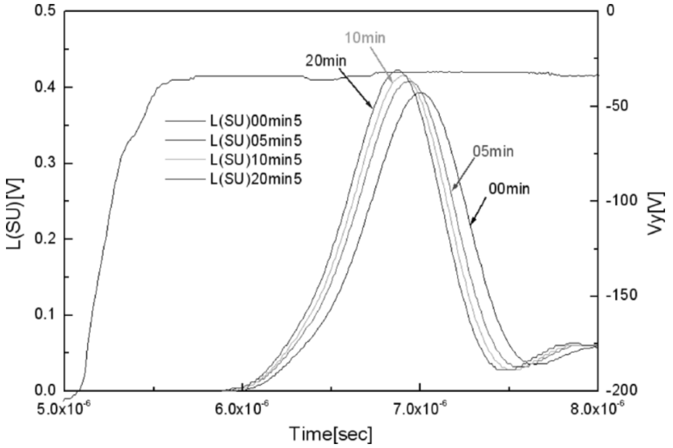


Fig. 14. Light emission waveforms for first sustain pulses as a function of operating time.

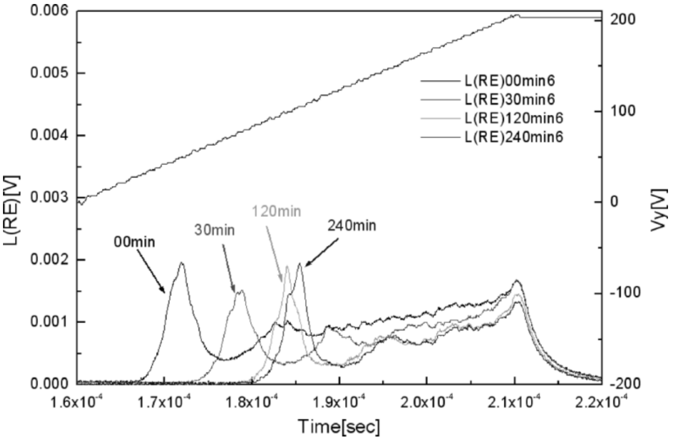


Fig. 15. Light emission waveforms for positive ramp reset period as a function of operating time (Case 6).

3) Case 6 (After 30 min Under Conditions of Case 5): Case 6 provided additional conditions to verify the temperature effect of the panel. As shown in Fig. 15, the saturation time for Case 6 was very long at around 240 min. In Case 6, the switching elements and the panel were stabilized high temperature due to 30 min operation under the conditions of Case 5. Therefore, it would appear that the increase in $\mathrm{Vyx(RE)d}$ was caused by the cooling effects of the panel and switching elements, which initially had a high temperature.

For the sake of comparison, Fig. 16 shows the initial light emission waveforms for Case 2 and Case 6 and those after the saturation time. The main difference between Case 2 and Case 6 was the initial panel temperature. Initially, the light emission waveforms varied significantly between Case 2 and Case 6, yet they were almost the same after the saturation time, thereby also reinforcing that the decrease in the breakdown voltage was due to the temperature effects.

IV. CONCLUSION

This paper investigated the temperature-dependent characteristics of ac PDPs based on various case studies. The resulting conclusions are as follows.

1) As the operating time of driving system is increased, the $\mathrm{Vyx(RE)d}$ is increased, which may be related to the change in the impedance of the circuit elements.

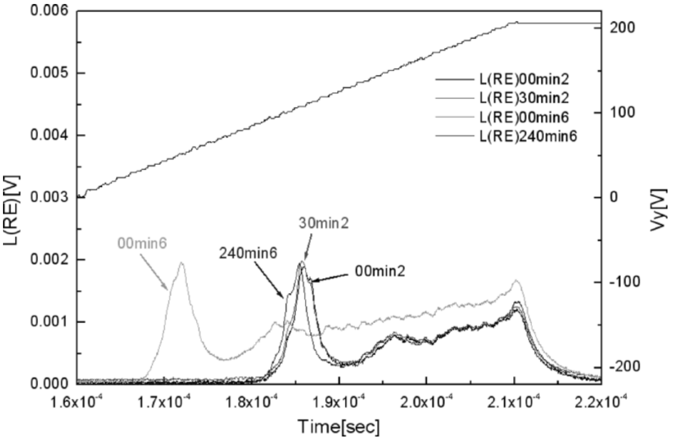


Fig. 16. Light emission waveforms for positive ramp reset period as a function of operating time (Case 2 and Case 6).

2) After driving system is stabilized, if there is no sustain discharge, the $\mathrm{Vyx(RE)d}$ is not changed. Therefore, it can be inferred that reset discharges are not related to the temperature-dependent characteristics.
3) The effect of the reactive power heating on the temperature-dependent characteristics is very weak under this test driving scheme.
4) As the panel temperature is increased due to the strong sustain discharges, the $\mathrm{Vyx(RE)d}$ is decreased. Therefore, it can be inferred that the breakdown voltage of pixel is decreased as the panel temperature is increased. Also, higher panel temperature is more effective to decrease the breakdown voltage of pixel.
5) As the panel temperature is increased, the intensity of the sustain discharge is increased due to the decreased breakdown voltage of pixel.

As such, these results may have relevance to image-sticking phenomena and reliability testing with high and low environmental temperatures [2], [12]. The former has been extensively studied, as it represents a serious problem in commercial PDP products. The image-sticking problem is the residual image or ghost image that remains in a subsequent image when the previous image was continuously displayed over a few minutes. There are two types of image-sticking: one is dark image sticking and the other is a bright image sticking. The dark image sticking occurs when a certain image is turned on for several minute, and then the image is turned off. In this condition, the previously turned on image remains brighter than the reset of the area. On the contrary, the bright image sticking occurs when a certain image is turned on for several minutes, and then turned on the rest of the area. In this condition, the previously turned-on image shows darker than the rest of the area. The light emission is only caused by reset discharges in the dark image-sticking while it is mainly caused by sustain discharges in the bright image-sticking.

Based on the results of this paper, the dark image sticking is caused by a lower breakdown voltage, which is created by increased panel temperature (possibly heated MgO surface or gas). In other words, the previously turned on pixels show a lower breakdown voltage, which results in reset discharges with a long emission time, thereby increasing the luminance in the reset period. Also, it may be helpful in understanding bright image-sticking phenomena, as the decreased luminance of high-temperature pixels is surely related to the phosphor layer rather than the intensity of the sustain discharges. Meanwhile, reliability tests under high and low temperature environments should consider the temperature dependency of both the panel characteristics and the circuit characteristics. Even though many areas still need to be understood more clearly, it is hoped that the present results will also prove helpful in clarifying temperature-related phenomena.

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