Discharge Characteristics of AC Plasma Display Panel Prepared Using Vacuum Sealing Method

Choon-Sang Park, Heung-Sik Tae, *Senior Member, IEEE*, Young-Kuk Kwon, and Eun Gi Heo

***Abstract*—The base vacuum level achieved before loading the discharge gas is known to be an important parameter that affects both the address and sustain discharge characteristics in an ac plasma display panel (PDP), as a higher base vacuum level improves the discharge characteristics. Accordingly, the vacuum sealing method, which can enhance the base vacuum level, is adopted to enhance the MgO characteristics by reducing any residual gas impurity. The resulting changes in the address and sustain discharge characteristics, including the secondary electron coefficient, firing voltage, and dynamic voltage margin, are then compared with the results when using conventional atmospheric-pressure sealing for a 42-in ac PDP with a high Xe (11%) content. The vacuum sealing method was found to improve the secondary electron emission coefficient, lower the firing voltage, particularly under MgO cathode conditions, and increase the dynamic voltage margin. However, the vacuum sealing was also found to deteriorate the visible transmittance of the dielectric layer in the front panel. Nonetheless, the vacuum sealing process enabled the use of a higher Xe content, which is up to 17%, under a stable dynamic margin voltage, thereby improving both the luminance and luminous efficiencies of the ac PDP.**

***Index Terms*—Dynamic voltage margin, higher Xe content (17%), impurity gas, luminance and luminous efficiencies, vacuum sealing method, visible transmittance, V_t closed curve.**

I. Introduction

ACHIEVING a higher base vacuum level before loading the discharge gas is known to improve the address and sustain discharge characteristics in plasma display panels (PDPs) [1]–[6]. In the case of a conventional 42-in ac PDP with a box-type barrier rib, the front and rear glasses are typically sealed under atmospheric pressure. The panel is then evacuated using a high-vacuum pump via a glass tip sealed to a corner of the rear glass. However, the resulting base vacuum level is limited by the pumping conductance of the panel, which, in turn, is mainly related to the barrier rib shape. Thus, in the case of a conventional 42-in ac PDP with a box-type barrier rib, the base vacuum level obtained in the center region and regions distant from the glass tip is only 10^{-2} torr. Therefore, to improve the base vacuum level, the vacuum sealing method has been adopted, where the front and rear glasses are sealed under a high-vacuum chamber, resulting in a base vacuum level of about 10^{-5} torr for a 42-in panel with a box-type barrier rib, along with a reduced total sealing time [5]–[12]. Moreover, the gas impurity level also strongly depends on the base vacuum level during the sealing process. In particular, the oxygen impurity level can have a significant effect on the MgO surface state. Consequently, the discharge characteristics of an ac PDP can be changed according to the base vacuum level during the sealing process.

Accordingly, this paper examines the resulting changes in the address and sustain discharge characteristics, including the dynamic voltage margin, firing voltage, secondary electron coefficient, and luminance efficiency, when applying the vacuum sealing method to enhance the base vacuum level, and then compares the results with those obtained when using the conventional sealing method for a 42-in ac PDP with a high Xe (11%) content and box-type barrier. The vacuum sealing process also enables a higher Xe (17%) content to be employed, thereby improving both the luminance and luminous efficiencies of the ac PDP.

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II. Experimental Setup

A. Vacuum Sealing and Conventional Atmospheric Pressure Sealing Processes

Fig. 1(a) and (b) shows a schematic diagram of the conventional atmospheric-pressure sealing process and detailed sealing temperature and pressure profiles for a 42-in test panel during the conventional sealing process, respectively, whereas Fig. 2(a) and (b) shows the vacuum sealing process and detailed sealing temperature and pressure profiles for a 42-in test panel during the vacuum sealing process, respectively. In both cases, the MgO surfaces in the 42-in test panels were grown using exactly the same growth method, which is ion-plating evaporation; only the sealing processes were different. As shown in Fig. 1(b), with the conventional sealing process, the front and rear glasses were initially sealed under an atmospheric pressure of 760 torr, and then, the panel was evacuated using a high-vacuum pump via a glass tip located in a corner of the rear glass. In this case, considering that the resulting base vacuum level was limited by the pumping conductance of the panel, as determined by the barrier rib shape, the base vacuum level achieved in the center region of the box-type barrier rib and regions distant from the glass tip was 10^{-2} torr, as shown in Fig. 1(b). After tipping the test panel off at a pressure of

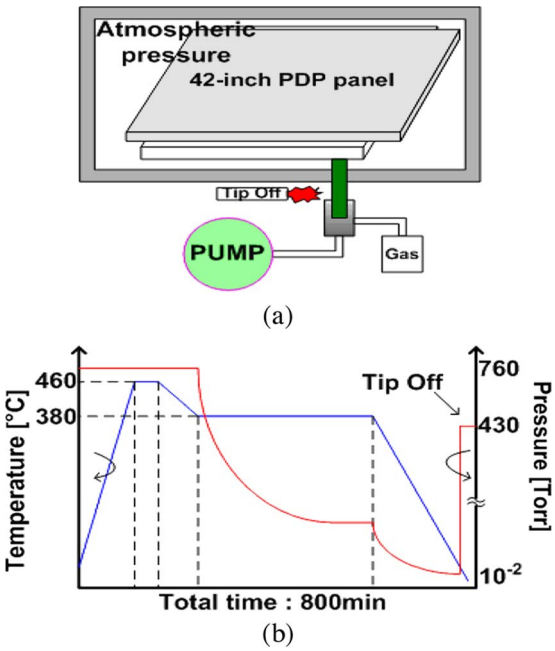

Fig. 1. (a) Schematic diagram of conventional atmospheric-pressure sealing process and (b) detailed sealing temperature and pressure profiles during conventional sealing process.

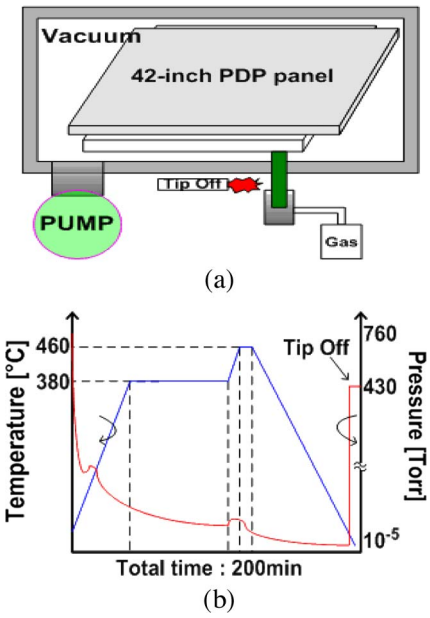

Fig. 2. (a) Schematic diagram of proposed vacuum sealing process and (b) detailed sealing temperature and pressure profiles during vacuum sealing process.

10^{-2} torr, the panel was then filled with gas to a pressure of 430 torr. Meanwhile, to obtain a higher base vacuum level, the vacuum sealing process was adopted instead of the conventional sealing process. As shown in Fig. 2(a), the front and rear glasses were sealed under a high-vacuum chamber, resulting in a base vacuum level of about 10^{-5} torr [5]–[12]. As shown in Fig. 2(b), after tipping the panel off at a pressure of 10^{-5} torr, the panel was then filled with gas to a pressure of 430 torr. In addition, the total sealing time was decreased by about 600 min, as shown in Figs. 1(b) and 2(b).

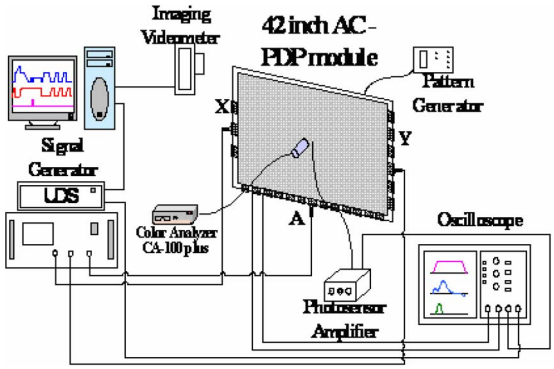

Fig. 3. Schematic diagram of experimental setup employed in this paper.

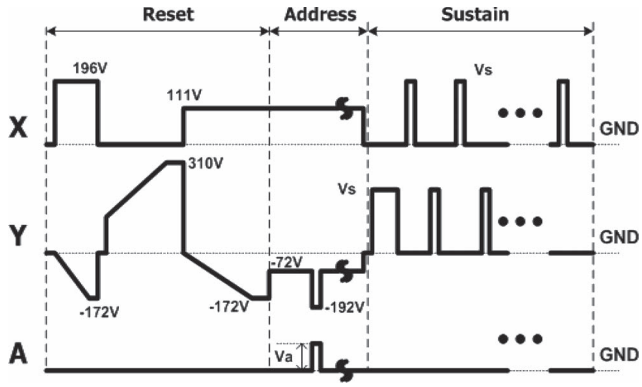

Fig. 4. Schematic diagram of driving waveform used in this paper.

TABLE I
SPECIFICATIONS OF 42-in AC PDP USED IN THIS PAPER

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 or 17 %)-He (35 %)	
Barrier rib type		Closed rib	

B. Measurement of Discharge Characteristics for Two Cases: Vacuum Sealing and Conventional Sealing Methods

Fig. 3 shows the optical-measurement systems and 42-in ac PDP module with three electrodes used in the experiments, where X is the sustain electrode, Y is the scan electrode, and A is the address electrode. A color analyzer (CA-100 plus), pattern generator, signal generator, and photosensor amplifier (Hamamatsu, C6386) were used to measure the luminance, IR emission, and V_t closed curve. Fig. 4 shows the driving waveforms, including the reset, address, and sustain periods, employed to compare the discharge characteristics of the 42-in test panels fabricated using the two different sealing methods. The frequency for the sustain period was 200 kHz. A driving method with a selective reset waveform was also adopted, and the gas chemistry in the experiment was Ne–Xe (11%)–He (35%) under a pressure of 430 torr. Table I lists the detailed specifications for the two test panels, which were exactly the same, except for the sealing process.

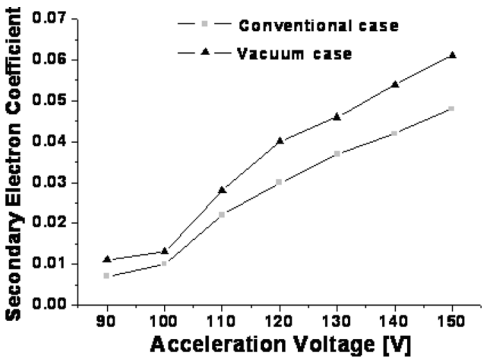

Fig. 5. Comparison of secondary electron coefficients for 42-in test panels with 11% Xe prepared using conventional and vacuum sealing methods.

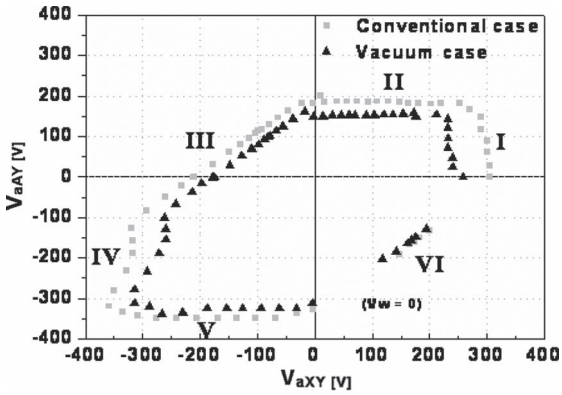

Fig. 6. Comparison of V_t closed curves for 42-in panels with 11% Xe prepared using conventional and vacuum sealing methods without initial wall charges, where I: VtXY (= discharge start threshold cell voltage between X and Y); II: VtAY (= discharge start threshold cell voltage between A and Y); III: VtAX (= discharge start threshold cell voltage between A and X); IV: VtYX (= discharge start threshold cell voltage between Y and X); V: VtYA (= discharge start threshold cell voltage between Y and A); and VI: VtXA (= discharge start threshold cell voltage between X and A).

III. Results and Discussion

A. Discharge Characteristics of AC PDPs Prepared Using Two Different Sealing Methods: Vacuum Sealing and Conventional Atmospheric-Pressure Sealing Methods

1) Comparison of Secondary Electron Emission Coefficients for Two Different Sealing Methods: Fig. 5 shows the changes in the secondary electron coefficients for the MgO layers sealed using the two different sealing methods, namely, conventional and vacuum sealing. The secondary electron emission for the MgO layer was measured using the γ-focused ion beam (FIB) system. The γ-FIB system measured the intensity of the electrons emitted from the MgO layer when the MgO surface was struck by the Ne^+ ions focused to a diameter of 80 μm by means of a single Einzel lens with ion acceleration energy ranging from 90 to 150 V [13]. As shown in Fig. 5, the secondary electron coefficient (γ process) for the MgO layer in the test panel prepared using the vacuum sealing method was higher than that for the MgO layer in the test panel prepared using the conventional sealing method, indicating that the MgO surface state was enhanced by simply changing the sealing process even with the same growth method. The secondary electron emission capability of the MgO layer has already been reported to be improved when increasing the oxygen vacant states in the MgO layer [5], [9]–[12]. Thus, the reduction in the gas impurity, particularly as regards oxygen, resulting from the vacuum sealing process, appeared to be strongly related to the enhanced secondary electron emission capability of the MgO layer.

2) Comparison of Firing Voltages Using V_t Closed Curves for Two Different Sealing Methods: Fig. 6 shows the changes in the V_t closed curves under no initial wall charges in 42-in test panels prepared using the two different sealing methods, namely, conventional and vacuum sealing. As shown in Fig. 6, in the case of vacuum sealing, the firing voltages for I(X–Y), II(A–Y), III(A–X), and IV(Y–X), i.e., the firing voltages under MgO cathode conditions, were significantly lower, whereas the firing voltages for V(Y–A) and VI(X–A), i.e., the firing voltages under phosphor cathode conditions, were only slightly lower. In the case of vacuum sealing, the reduced residual impurity level [11] results in lowering the firing voltage. The low residual impurity level contributes to enhancing the ionization capability within the gas space (i.e., α value) in addition to improving the secondary electron emission coefficient (i.e., γ value). Consequently, the low firing voltage was obtained by the sum of the two factors, that is, one factor was the improvement of the γ value induced by the better secondary electron emission coefficient (γ process), and the other was the improvement of the α value caused by the low residual impurity level (α process). However, it is not clear which factor is more dominant for lowering the firing voltage. The variations in the firing voltages measured under the MgO and phosphor cathode conditions for the 42-in test panels prepared using the two different sealing methods are listed in Table II.

TABLE II
Firing Voltages Measured for 42-in Test Panels Prepared Using Conventional Atmospheric and Vacuum Sealing Methods

Region		Firing voltage	
		Conventional sealing method	Vacuum sealing method
MgO Cathode	I	300V	232V
	II	184V	152V
	III	210V	178V
	IV	328V	292V
Phosphor Cathode	V	350V	324V
	VI	340V	326V

3) Comparison of Dynamic Voltage Margins With Two Different Sealing Methods: Fig. 7(a) shows the changes in the dynamic voltage margins measured using the driving waveform in Fig. 4 when 42-in test panels with 11% Xe were sealed using the conventional and vacuum sealing methods. As shown in Fig. 7(a), the address and sustain dynamic voltage margins with the vacuum sealing method were greater than those with the conventional sealing method. In particular, with the vacuum sealing method, the sustain and address voltages were decreased by about 30 and 7 V, respectively, under the Xe (11%) gas chemistry conditions. Thus, the reduced firing voltages and increased dynamic voltage margin with the vacuum sealing enabled an additional increase in the Xe percentage in the Ne–Xe–He gas chemistry.

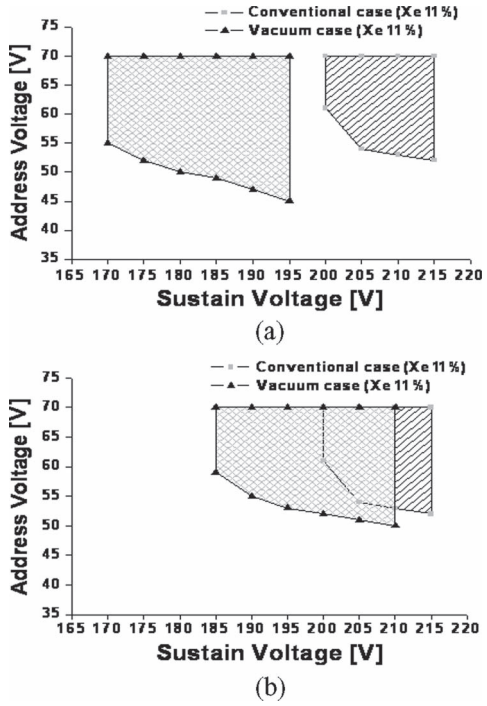

Fig. 7. (a) Dynamic voltage margins measured for 42-in test panels prepared using conventional (Xe: 11%) and vacuum sealing (Xe: 11%) methods. (b) Dynamic voltage margins measured in 42-in test panels prepared using conventional (Xe: 11%) and vacuum sealing (Xe: 17%) methods.

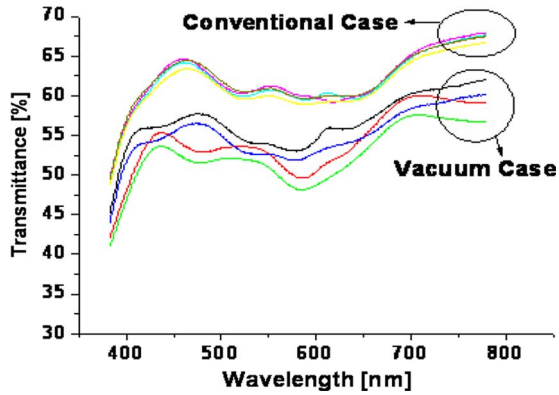

Fig. 8. Comparison of transmittances for 42-in front panels prepared using conventional and vacuum sealing methods.

Fig. 7(b) shows the changes in the dynamic voltage margin for 42-in panels with different percentages of Xe, where a test panel with 11% Xe was sealed using the conventional atmospheric sealing method and a test panel with 17% Xe was sealed using the vacuum sealing method. As shown in Fig. 7(b), in the case of vacuum sealing, the dynamic voltage margin was greater, with a lower sustain voltage, although the Xe content was increased from 11% to 17%. Consequently, the vacuum sealing method enabled the use of a higher Xe percentage without decreasing the dynamic voltage margin, thereby improving the luminance and luminous efficiencies of the PDP.

4) Comparison of Transmittance for Two Different Sealing Methods: Fig. 8 shows the changes in the visible transmittances, ranging from 380 to 780 nm, measured in 42-in panels prepared using conventional and vacuum sealing. In the case of the vacuum sealing, the color of the dielectric layer in the front panel changed from being transparent to slightly yellow, resulting in a reduction of the visible transmittance in the front panel, as shown in Fig. 8. Unlike the case of conventional atmospheric sealing, the high-vacuum (= about 10^{-5} torr) condition during the vacuum sealing process may have caused some evaporation of the metal components in the dielectric layer in the front panel, thereby changing the color of the metal-deficient dielectric layer to slightly yellowish. This phenomenon is deeply related to the oxygen deficiency induced by the vacuum sealing, that is, for high-vacuum sealing, oxygen deficiency is more likely to have induced the discoloration of the dielectric layer. Thus, although the vacuum sealing process lowered the firing voltage of the PDP cells, it also caused a decrease in the visible transmittance of the dielectric layer in the front panel.

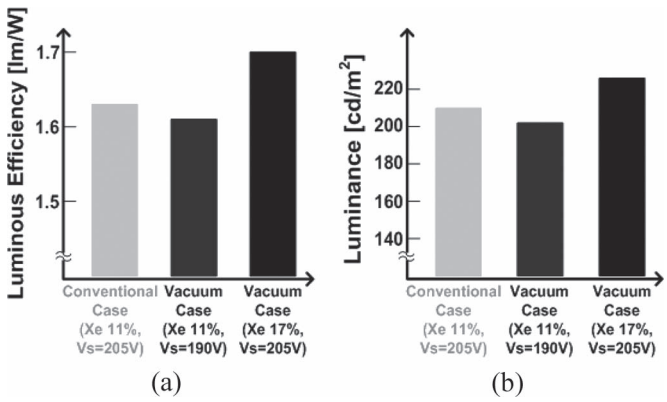

Fig. 9. Comparison of (a) luminous efficiencies and (b) luminance for 42-in panels prepared using conventional (Xe: 11%, Vs = 205 V) and vacuum sealing (Xe: 11%, Vs = 190 V and Xe: 17%, Vs = 205 V) methods.

B. Improvement of Luminance and Luminous Efficiencies Using Higher Xe Content in AC PDP Prepared Using Vacuum Sealing Process

Fig. 9 shows the changes in the luminance and luminous efficiencies in 42-in panels fabricated under different Xe contents by using the conventional (Xe: 11%, Vs = 205 V) and vacuum (Xe: 11%, Vs = 190 V and Xe: 17%, Vs = 205 V) sealing processes. For the vacuum sealing case with 11% Xe, the luminance efficiency was decreased due to the aggravated visible transmittance despite the improvement of the discharge characteristics such as a firing voltage and dynamic margin. On the other hand, for the 42-in panel fabricated using vacuum sealing with 17% Xe, the luminance and luminous efficiencies were both increased compared with those for the panel fabricated using conventional sealing with 11% Xe at the same sustain voltage of 205 V, as shown in Fig. 9. Thus, the ability to use a higher Xe content under low sustain voltage operation conditions with the vacuum sealing method enhanced both the luminance and luminous efficiencies of the 42-in ac PDP.

IV. Conclusion

The vacuum sealing method was applied to enhance the discharge characteristics of an ac PDP by reducing the impurity

level, particularly the oxygen level. When comparing the effect of vacuum sealing and conventional atmospheric-pressure sealing on the secondary electron emission coefficient, firing voltage and dynamic voltage margin vacuum sealing was found to improve the secondary electron emission coefficient, lower the firing voltage, particularly under MgO cathode conditions, and increase the dynamic voltage margin. However, vacuum sealing was also found to deteriorate the visible transmittance of the dielectric layer in the front panel. Nonetheless, the vacuum sealing process facilitated the use of a higher Xe content, which is up to 17%, under a stable dynamic margin voltage, thereby improving both the luminance and luminous efficiencies of the ac PDP.

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