# Reduction of permanent image sticking in ACPDPs using RF-plasma pretreatment on MgO surface

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# Reduction of permanent image sticking in ACPDPs using RF-plasma pretreatment on MgO surface

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***Abstract*** — The characteristics of the MgO layer are known to be an important parameter that affects the permanent image sticking or lifetime of an ACPDP. In this paper, to reduce the permanent image sticking in ACPDPs, the effects of RF-plasma pretreatments of the MgO layer on the permanent image sticking are investigated. The treatment was conducted by using several plasma-forming gases, including Ar, Ar followed by $O_2$, and $O_2$ followed by Ar. Measurements of luminance, normalized luminance, $V_t$ closed curve, haze, MgO hardness, and photoluminescence between the discharge and nondischarge regions under dark and bright backgrounds indicated that the plasma treatments of MgO using either Ar or Ar followed by $O_2$ gases reduce the permanent image sticking on dark and bright images in an ACPDP.

***Keywords*** — *RF-plasma pretreatment, permanent image sticking, MgO layer, haze, cathodoluminescence (CL), photoluminescence (PL), ACPDP.*

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## 1 Introduction

To realize a high-quality plasma-display panel (PDP), the phenomena of image sticking and image retention must be significantly reduced. The phenomena occur when strong sustain discharges are repeated in the PDP cells during a sustain period.[1–12] While the image retention is only temporal and easily recoverable,[1–5] the image sticking is permanent and not recoverable.[6–12] The sputtering of the MgO surface by ions during the repeated strong sustain discharges causes severe degradation of the MgO surface and the phosphor layer, eventually resulting in the image-sticking phenomena.[6–8] The sputtering characteristics strongly depend on the properties of the MgO surface, especially the sputter resistance of the MgO surface. Thus, a decrease in the sputtering of the MgO layer could reduce permanent image sticking.

In this paper, the RF-plasma pretreatments on the MgO layer under various plasma gases, Ar, Ar followed by $O_2$, and $O_2$ followed by Ar, are adopted to reduce the sputtering of the MgO layer. The resultant changes in the permanent image-sticking characteristics on the dark and bright images, such as the display luminance, normalized luminance, and $V_t$ closed curve, were examined in comparison with the as-deposited MgO layer in a 50-in. full-HD ACPDP with a Ne–Xe (11%)–He (35%) gas-mixture content.

## 2 Experimental setup

Figure 1 shows the optical measurement systems and the 50-in. full-HD ACPDP 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) and pattern generator were used to measure the luminance. In order to induce permanent image sticking, the entire region of the 50-in. test panel was changed either to dark or to full-white backgrounds after displaying a square-type image (discharge region A) for a peak-white pattern. By using the automatic power-control system of the PDP, 850 sustain pulses were alternately applied to the X and Y electrodes during one TV field (= 16.67 msec) to display a square-type test image. The image occupies an area of 1% of the central region of a 50-in. panel. The full-white background (entire region) corresponds to the operation condition where 270 sustain pulses are alternately applied to the X and Y electrodes per one TV field. On the other hand, the dark background (entire region) denotes the condition that only a weak reset discharge is applied per each TV field without sustain discharge. After displaying a square-type image (discharge region A) for various time intervals ranging from 0 to 1000 hours, the entire region of the 50-in. test panel was displayed, and the lumi-

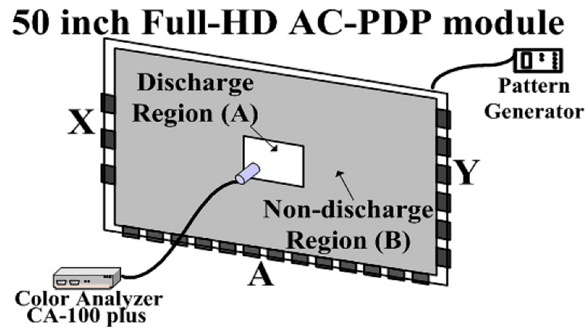


**FIGURE 1** — Schematic diagram of experimental setup employed in this research.

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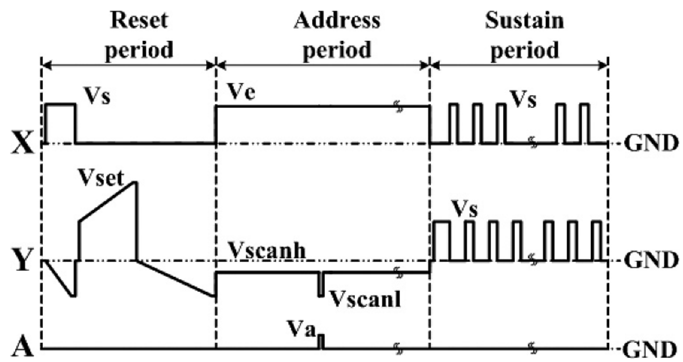


**FIGURE 2** — Schematic diagram of typical driving waveform used in this study.

nance difference between the discharge (A) and nondischarge (B) regions was evaluated. The luminance was reduced in the discharge (A) region with an increase in the displayed time of the square-type image. A normalized luminance was used to evaluate the effects of RF-plasma pretreatment on the permanent image sticking either on dark or bright backgrounds. Here, the normalized luminance was defined as the ratio of the luminance difference between the initial luminance and the luminance with a specific displayed time in the discharge (A) region. Thus, a normalized luminance of 1 corresponds to no luminance difference between the discharge (A) and nondischarge (B) regions, implying no image sticking.

Figure 2 shows the driving waveforms, including the reset, address, and sustain periods, employed to compare the permanent image-sticking characteristics of the 50-in. full-HD test panels with and without the RF-plasma pretreatments. The frequency of the sustain period was 200 kHz. A driving method with a selective reset waveform was also adopted, and the composition of the discharge gas was Ne–Xe (11%)–He (35%) under a pressure of 430 Torr. Our previous experimental results showed that plasma pretreatments using either Ar or Ar followed by $O_2$ plasma gases could reduce the firing voltage by increasing the secondary-electron-emission coefficient of the MgO layer.[13] Accordingly, during the experiment, different voltage levels of the driving waveforms were applied to each test panel, considering the different firing voltages, as listed in Table 1.

**TABLE 1** — Optimal voltage levels applied to test panels with different plasma pretreatment conditions.

| Panel | Voltage [V] | | | | | |
|---|---|---|---|---|---|---|
| | $V_s$ | $V_{set}$ | $V_{scanh}$ | $V_{scanl}$ | $V_e$ | $V_a$ |
| Ref. #1, #2 | 206 | 325 | –55 | –175 | 95 | 65 |
| $O_2$ > Ar #1, #2 Plasma pretreatment | 206 | 325 | –55 | –175 | 95 | 65 |
| Ar Plasma pretreatment | 196 | 315 | –55 | –175 | 95 | 65 |
| Ar > $O_2$ Plasma pretreatment | 200 | 319 | –55 | –175 | 95 | 65 |

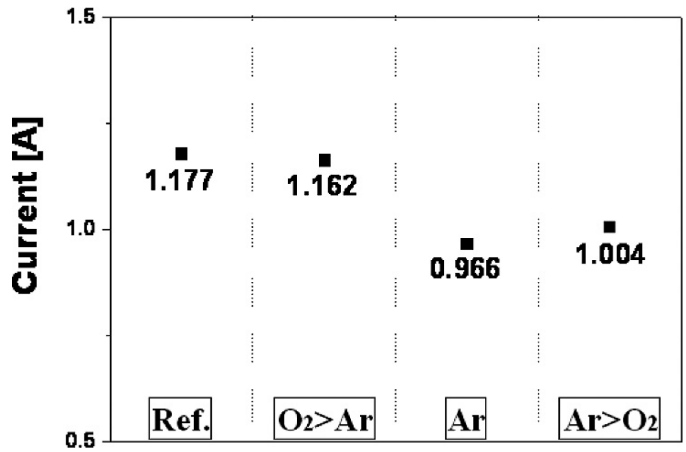


**FIGURE 3** — Changes in discharge currents relative to RF-plasma pretreatment on MgO layer with various plasma gases: $O_2$ > Ar, Ar, and Ar > $O_2$ for peak-white pattern.

Figure 3 shows the changes in the discharge current relative to the RF-plasma pretreatment of the MgO layer with various plasma gas compositions for a peak-white pattern. As shown in Fig. 3, in both cases of Ar (240 sccm) and Ar followed by $O_2$ [gas mixture: Ar > $O_2$ (Ar, 189 sccm (main gas) and $O_2$, 21 sccm (additional gas))] plasma pretreatments, the discharge currents for a peak-white pattern were reduced compared to the panel without plasma pretreatment (Ref. panel) and $O_2$ followed by Ar [gas mixture: $O_2$ > Ar ($O_2$, 201 sccm (main gas) and Ar, 22 sccm (additional gas))] plasma pretreatment. The reduction in the discharge current results in a decrease in the number of ions generated during the discharge.[14,15]

Figure 4 shows a schematic diagram of the RF-plasma equipment used for the plasma pretreatment. Tables 2 and 3 show the specifications of the RF-plasma pretreatment

**TABLE 2** — Specifications of plasma pretreatment conditions employed in this research.

| Plasma pretreatment condition (set-up) | |
|---|---|
| Plasma type | RIE (Reactive ion etching) plasma generator |
| Vacuum pump | Dry pump (base pressure: 4.3 mTorr) |
| RF (13.56 MHz) input power | 4 kW |
| Operating pressure | 100 mTorr |
| Process time | 30 min |

**TABLE 3** — Specifications of various plasma-pretreatment gas compositions employed in this research.

| Plasma pretreatment gas compositions | |
|---|---|
| Ref. #1, #2 | Without plasma pretreatment |
| $O_2$ > Ar #1, #2 Plasma pretreatment | $O_2$ (201 sccm) + Ar (22 sccm) |
| Ar Plasma pretreatment | Ar (240 sccm) |
| Ar > $O_2$ Plasma pretreatment | Ar (189 sccm) + $O_2$ (21 sccm) |

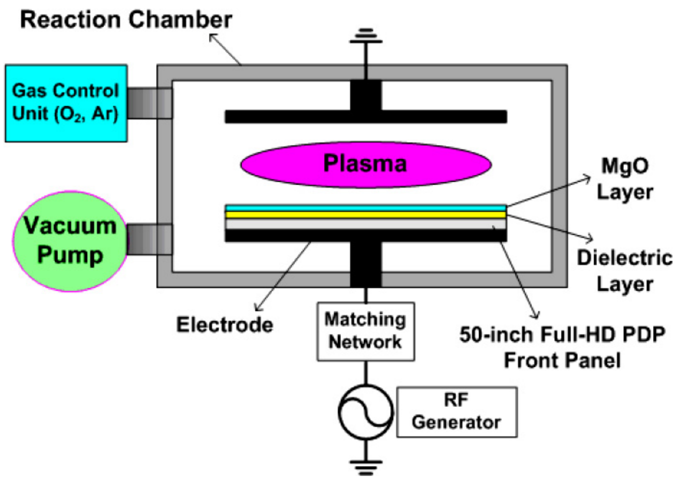


**FIGURE 4** — Schematic diagram of capacitive-type RF-plasma equipment used for plasma pretreatment on MgO layer.

condition and various plasma pretreatment gas compositions employed in this research. The detailed panel specifications are listed in Table 4. The RF (13.56 MHz) input power and the process time for plasma pretreatment were 4 kW and 30 minutes, respectively.[13,16,17]

## 3 Experimental observation of permanent image sticking with and without RF-plasma pretreatment on MgO layer

### 3.1 Display luminance under dark and full-white backgrounds and normalized luminance under full-white background

Tables 5 and 6 show the luminance difference between the discharge (A) and nondischarge (B) regions under a dark background (Table 5) and a full-white background (Table 6) after 1000 hours of strong sustain discharge with a square-type image, measured for a 50-in. full-HD panels with and without the RF-plasma pretreatments on the MgO layer under various plasma gases: Ref. (without plasma pretreatment), $O_2$ > Ar, Ar, and Ar > $O_2$ plasma pretreatments. As shown in Tables 5 and 6, for $O_2$ > Ar plasma pretreatment, the luminance difference between the discharge (A) and nondischarge (B) regions under dark and full-white backgrounds were almost the same as that for the panel without plasma pretreatment (Ref. panel). However, in both cases of Ar and Ar > $O_2$ plasma pretreatments, the luminance difference between the discharge (A) and nondischarge (B) regions under dark and full-white backgrounds were remarkably reduced when compared with the panel without pretreatment (Ref. panel). It is expected that the Ar and Ar > $O_2$ plasma pretreatments will contribute to reducing the permanent image sticking on the dark and bright images of the ACPDP TV.

Figure 5 shows the changes in the normalized luminance in the discharge region (A) measured under a full-white background immediately after displaying the square-type image for up to 1000 hours on the 50-in. test panels. As mentioned previously, the normalized luminance in Fig. 5

**TABLE 4** — Specifications of the 50-in. FHD ACPDP used in this study.

| Front panel | | Rear panel | |
|---|---|---|---|
| ITO width | 210 μm | Barrier rib width | 50 μm |
| ITO gap | 70 μm | Barrier rib height | 120 μm |
| Bus width | 70 μm | Address width | 85 μm |
| Pixel pitch | | 576 × 576 μm | |
| Gas chemistry | | Ne–Xe (11%)–He (35%) | |
| Gas pressure | | 430 Torr | |
| Barrier rib type | | Closed rib | |

**TABLE 5** — Changes in luminance in discharge (A) and nondischarge (B) regions under dark background after 1000 hours of sustain discharge measured for a 50-in. full-HD panel using RF-plasma pretreatment on the MgO layer for various gas compositions.

| Panel | Luminance ($cd/m^2$) | | |
|---|---|---|---|
| | Region A ($L_1$) | Region B ($L_2$) | $\Delta L$ (=$\lvert L_2 - L_1\rvert$) |
| Ref. #1 | 0.22 | 0.18 | 0.04 |
| Ref. #2 | 0.19 | 0.22 | 0.03 |
| $O_2$ > Ar #1 | 0.19 | 0.21 | 0.02 |
| $O_2$ > Ar #2 | 0.28 | 0.21 | 0.07 |
| Ar | 0.15 | 0.16 | 0.01 |
| Ar > $O_2$ | 0.21 | 0.22 | 0.01 |

**TABLE 6** — Changes in luminance in discharge (A) and nondischarge (B) regions under a full-white background after 1000 hours of sustain discharge measured for a 50-in. full-HD panel using RF-plasma pretreatment on the MgO layer for various gas compositions.

| Panel | Luminance ($cd/m^2$) | | |
|---|---|---|---|
| | Region A ($L_1$) | Region B ($L_2$) | $\Delta L$ (=$\lvert L_2 - L_1\rvert$) |
| Ref. #1 | 131.8 | 165.3 | 33.5 |
| Ref. #2 | 135.9 | 181.6 | 45.7 |
| $O_2$ > Ar #1 | 132.0 | 168.2 | 36.2 |
| $O_2$ > Ar #2 | 115.0 | 140.3 | 25.3 |
| Ar | 125.0 | 134.0 | 9 |
| Ar > $O_2$ | 139.5 | 148.0 | 8.5 |

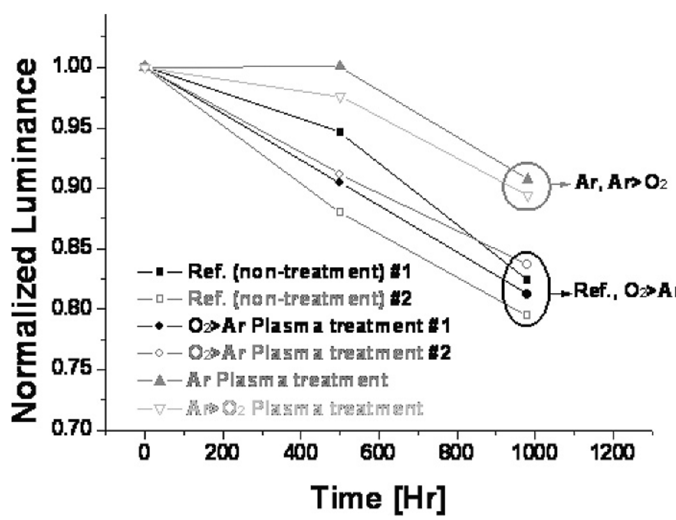


**FIGURE 5** — Normalized luminance in region A relative to display time of square-type image measured for a 50-in. full-HD panel with and without RF-plasma pretreatment on the MgO layer under various plasma gases: $O_2$ > Ar, Ar, and Ar > $O_2$.

was calculated by the luminance difference in the discharge (A) region under a full-white background. As shown in Fig. 5, the normalized luminance decreased with an increase in the display time of a square-type image. In both cases of Ar and Ar > $O_2$ plasma pretreatments, after 1000 hours of strong sustain discharge with a square-type image, the normalized luminance was observed to be higher than that in both cases without plasma pretreatment: Ref. panel and $O_2$ > Ar. This result indicates that the Ar and Ar > $O_2$ plasma pretreatments on the MgO layer contribute in reducing permanent image sticking.

## 3.2 Difference in firing voltages using $V_t$ closed curves

To investigate the reason for enhanced permanent image sticking on the dark and bright images in both cases of the Ar and Ar > $O_2$ plasma pretreatments, the $V_t$ closed curves were measured for both the discharge (A) and nondischarge (B) regions in the red cells with and without the RF-plasma pretreatment. In general, for the discharge region, the firing voltages for sides I (X–Y), II (A–Y), III (A–X), and IV (Y–X) under MgO-cathode conditions were almost the same as those for the nondischarge region.[6–10] However, the firing voltages of the discharge region for sides V (Y–A) and VI (X–A) under phosphor-cathode conditions were greatly reduced when compared with the firing voltages of the nondischarge region.[6–10] As a result, a significant reduction in the firing voltage under phosphor-cathode conditions in the discharge (A) region confirmed that a significant amount of Mg species with a higher secondary-electron-emission coefficient was deposited on the phosphor layer. In this case, the Mg species on the phosphor layer were believed to originate from MgO sputtered from the region where strong sustain discharge had been repeatedly applied. Therefore, the reduction in the firing voltage under phosphor-cathode conditions showed that the decrease in the luminance of the image-sticking cell (discharge region A) could be attributed to the prohibition of a visible conversion from the vacuum ultraviolet (VUV) of the phosphor layers caused by Mg deposition onto the phosphor layers, instead of the deterioration of the phosphor layer itself.[6,7]

Figure 6 shows the firing voltage difference between the discharge (A) and nondischarge (B) regions in red cells with and without the RF-plasma pretreatment on the MgO layer under various plasma gases, $O_2$ > Ar, Ar, and Ar > $O_2$. For the case of without plasma pretreatment (Ref. panel), there was a large firing voltage difference (= 74.4 V) between the discharge (A) and nondischarge (B) regions under a phosphor-cathode condition, implying that the large firing voltage difference was presumably due to the recrystallization of Mg species with the phosphor layer. As shown in Fig. 6, in the case of $O_2$ > Ar plasma pretreatment, the difference in the firing voltages between the discharge (A) and nondischarge (B) regions under a phosphor-cathode condition was almost the same compared to the panel without

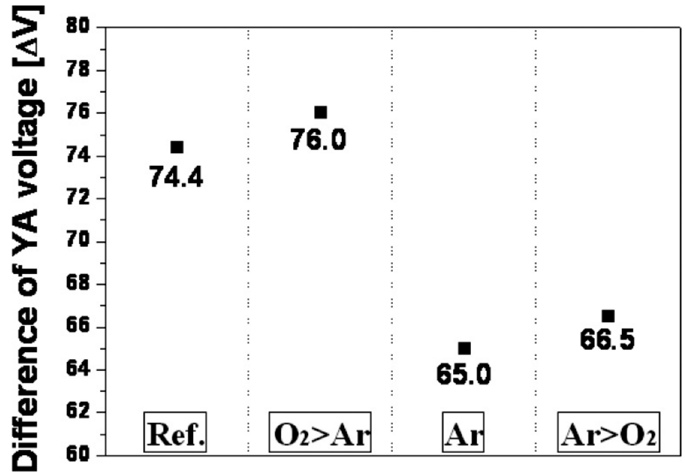


**FIGURE 6** — Comparison of firing voltage differences (= $\Delta Vt_{Y-A}$) between discharge (A) and nondischarge (B) regions relative to RF-plasma pretreatment on the MgO layer under various plasma gases, $O_2$ > Ar, Ar, and Ar > $O_2$. The firing voltages were measured using the $V_t$ closed curve method for red cell after 1000 hours of sustain discharge for a 50-in. full-HD panel with and without RF-plasma pretreatment on MgO layer under various plasma gases: $O_2$ > Ar, Ar, and Ar > $O_2$.

plasma pretreatment (Ref. panel). However, in both cases of Ar and Ar > $O_2$ plasma pretreatments, the differences in the firing voltages between the discharge (A) and nondischarge (B) regions under the phosphor-cathode condition were smaller compared to the panel without plasma pretreatment (Ref. panel) and $O_2$ > Ar plasma pretreatment. In both cases of Ar and Ar > $O_2$ plasma pretreatments, the reduction in the difference in firing voltage under the phosphor-cathode condition was due to the lesser amount of deposition of Mg species with a higher secondary-electron-emission coefficient on the phosphor layer. These experimental results showed that the reduction in the permanent image sticking in both cases of the Ar and Ar > $O_2$ plasma pretreatments could be attributed to less prohibition of visible conversion of the vacuum ultraviolet (VUV) of the phosphor layers caused by a smaller amount of Mg deposition onto the phosphor layers.[6–8]

# 4 Analysis of reduction of permanent image sticking induced by RF-plasma pretreatment on MgO layer

To identify the Mg species deposited on the phosphor layer and observe the surface morphology, haze, roughness, hardness, and defect level of the MgO layer, various measurements were carried out in this experiment as follows: the FE-SEM (field-emission scanning electron microscope) for surface morphology, a Haze Meter NDH 5000W for haze, an AFM (atomic-force microscope) for roughness, a Nanoindentor for hardness, CL (cathodoluminescence) for the defect level, and PL (photoluminescence) for analyzing the photointensity emitted from the phosphor layers.

## 4.1 Surface morphology and haze of MgO layers

Figure 7 shows a comparison of the SEM images of the MgO surface changes in discharge (A) and nondischarge (B) regions after 1000 hours of sustain discharge in the 50-in. full-HD panels with and without the RF-plasma pretreatment on the MgO layer. Table 7 shows the changes in the hazes of the MgO layer in discharge (A) and nondischarge (B) regions with and without the RF-plasma pretreatment. The haze, *HZ,* is defined as:

$$HZ = \frac{DF}{TT} \times 100\,(\%),$$

$$TT = DF + PT,$$

where *DF* is the diffuse transmission, *PT* is the parallel transmission, and *TT* is the total transmission. An increase in the haze caused an increase in light scattering on the MgO surface, thus resulting in a decrease in luminance. Accordingly, an increase in the haze difference, $\Delta H$, between the discharge (A) and nondischarge (B) regions results in permanent image sticking. As shown in the nondischarge (B) of Fig. 7, for $O_2$ > Ar plasma pretreatment, the surface morphology of the MgO layer was almost the same as the panel without plasma pretreatment (Ref. panel). However, in both cases of Ar and Ar > $O_2$ plasma pretreatments, the surface morphologies of the MgO layer were considerably changed to become smooth. The pyramidal morphologies of the MgO surfaces were eliminated in both cases of Ar and Ar > $O_2$ plasma pretreatments, as shown by the SEM image in Fig. 7. This elimination was mainly due to the physical sputtering caused by the ion bombardment during the Ar and Ar > $O_2$ plasma pretreatments. On the other hand, as shown in the discharge (A) regions of Fig. 7, the surface morphologies of the MgO layer were very similar regardless of the plasma pretreatments compared with the panel without plasma pretreatment (Ref. panel). However, as shown in Table 7, in both cases of Ar and Ar > $O_2$ plasma pretreatments, the haze difference, $\Delta H$, was greatly reduced compared to the panel without the plasma pretreatment (Ref. panel) and $O_2$ > Ar plasma pretreatment. This reduction in the haze difference was mainly due to a decrease in the light scattering on the MgO surface as a result of smoothing the MgO surface by physical sputtering during the Ar and Ar > $O_2$ plasma pretreatments. For both cases without plasma pretreatment and $O_2$ > Ar plasma pretreatment, the haze of the MgO surfaces in the discharge (A) region was greatly increased, compared to the nondischarge (B) region. During the sustain discharge, the MgO surface was sputtered and re-deposited due to ion bombardment, such that the haze of the MgO surface was increased. On the other hand, for both cases of Ar and Ar > $O_2$ plasma pretreatment, the haze on the MgO surfaces in the discharge (A) region was slightly increased, indicating that during the sustain discharge, the MgO surfaces pretreated by the Ar or Ar > $O_2$ plasma were less sputtered and less re-deposited than those pretreated by the $O_2$ > Ar plasma or without pretreatment.

**TABLE 7** — Changes in haze in discharge (A) and nondischarge (B) regions of the MgO surface measured after 1000 hours of sustain discharge for a 50-in. full-HD panels with and without RF-plasma pretreatment on the MgO layer.

| Panel | Haze (%) | | |
|---|---|---|---|
| | Discharge (A) region ($H_2$) | Non-discharge (B) region ($H_1$) | $\Delta H$ ($=\lvert H_2 - H_1\rvert$) |
| Ref. | 37.84 | 24.41 | 13.43 |
| $O_2$ > Ar | 32.71 | 22.12 | 10.59 |
| Ar | 25.05 | 21.04 | 4.01 |
| Ar > $O_2$ | 28.02 | 21.09 | 6.93 |

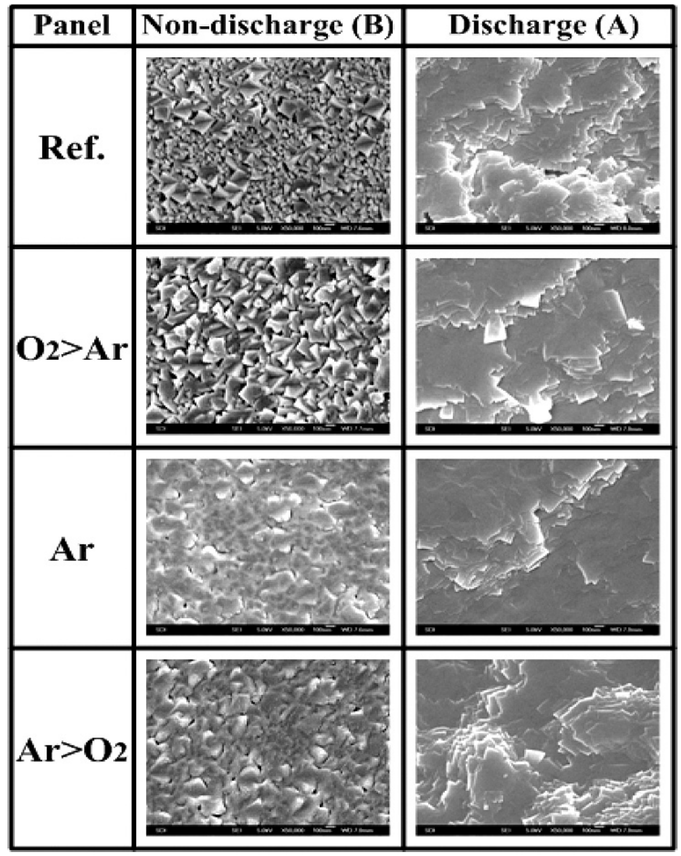


**FIGURE 7** — Comparison of SEM images of MgO surface changes in discharge (A) and nondischarge (B) regions measured after 1000 hours of sustain discharge for a 50-in. full-HD panel with and without RF-plasma pretreatment on the MgO layer under various plasma gases: $O_2$ > Ar, Ar, and Ar > $O_2$.

## 4.2 Roughness and hardness of MgO layers

Figure 8 and Table 8 show the changes in the three-dimensional AFM images and the roughness of the MgO surfaces in regions A and B after 1000 hours of sustain discharge with and without the RF-plasma pretreatment on the MgO layer, respectively. As shown in Fig. 8 and Table 8, in the nondischarge (B) region, for $O_2$ > Ar plasma pretreatment, the roughness of the MgO layer was slightly reduced compared to the panel without plasma pretreatment (Ref. panel). However, as shown in Fig. 8 and Table 8, in both cases of Ar

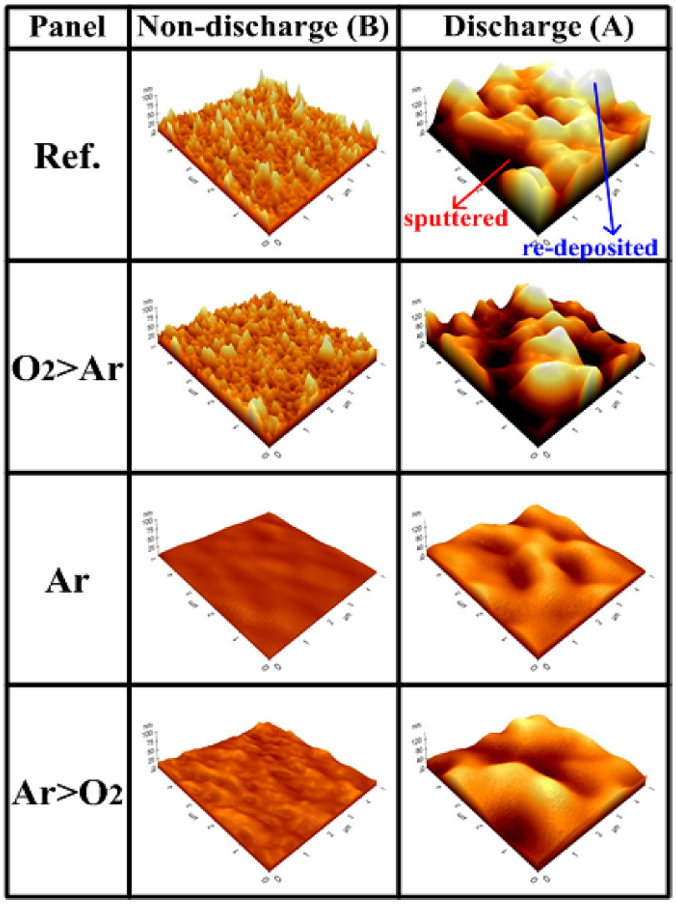


**FIGURE 8** — Comparison of AFM images of MgO surface changes in discharge (A) and nondischarge (B) regions after 1000 hours of sustain discharge measured for a 50-in. full-HD panel using RF-plasma pretreatment on the MgO layer under various plasma gases: $O_2$ > Ar, Ar, and Ar > $O_2$.

and Ar > $O_2$ plasma pretreatments, the roughness of the MgO layer was greatly reduced compared to the panel without plasma pretreatment. As described in the experimental results regarding haze, this reduction in the surface roughness was mainly due to the physical sputtering caused by the ion bombardment during the Ar and Ar > $O_2$ plasma pretreatments. Compared with the nondischarge (B) regions, in both cases without plasma pretreatment and $O_2$ > Ar plasma pretreatment, the roughness of the MgO surfaces in discharge region (A) was greatly increased. However, in both cases of Ar and Ar > $O_2$ plasma pretreatments, the roughness on the MgO surfaces in discharge region (A) slightly increased, indicating that during the sustain discharge, the MgO surfaces pretreated by the Ar or Ar > $O_2$ plasma were less sputtered and less re-deposited than those pretreated by the $O_2$ > Ar plasma or without pretreatment.

**TABLE 8** — Changes in roughness in discharge (A) and nondischarge (B) regions of MgO surface measured after 1000 hours of sustain discharge for a 50-in. full-HD panel with and without RF-plasma pretreatment on the MgO layer.

| Panel | Roughness (rms, Å) | | |
|---|---|---|---|
| | Discharge (A) region ($R_2$) | Non-discharge (B) region ($R_1$) | ΔR (=$\lvert R_2 - R_1 \rvert$) |
| Ref. | 399.7 | 109.6 | 290.1 |
| $O_2$ > Ar | 358.8 | 92.9 | 265.9 |
| Ar | 127.4 | 15.0 | 112.4 |
| Ar > $O_2$ | 196.9 | 35.8 | 161.1 |

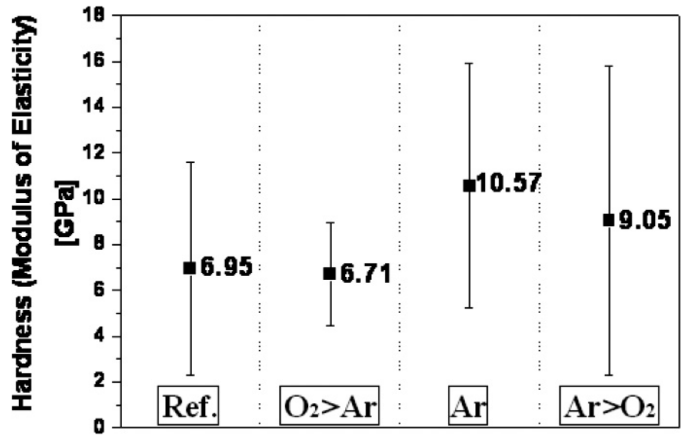


**FIGURE 9** — Comparison of MgO hardness of MgO layers measured using a nanoindentor for a 50-in. full-HD panel with and without RF-plasma pretreatment on the MgO layer under various plasma gases: $O_2$ > Ar, Ar, and Ar > $O_2$.

Figure 9 shows the changes in the hardness of the MgO layers measured by using a nanoindentor[8] in the 50-in. full-HD panels with and without RF-plasma pretreatment on the MgO layer under various plasma gases: $O_2$ > Ar, Ar, and Ar > $O_2$. As shown in Fig. 9, in both cases of Ar and Ar > $O_2$ plasma pretreatments, the hardness of the MgO layers increased compared to the panel without plasma pretreatment and $O_2$ > Ar plasma pretreatment, indicating that the MgO surface property was enhanced by simply changing the pretreatment process even with the same growth method and material. This means that the MgO layers pretreated by the Ar and Ar > $O_2$ plasmas were harder compared to those in both cases of without plasma pretreatment and $O_2$ > Ar plasma pretreatment.

Figure 10 shows a comparison of the cathodoluminescence (CL) spectra[18] of the MgO layers measured for 50-in.

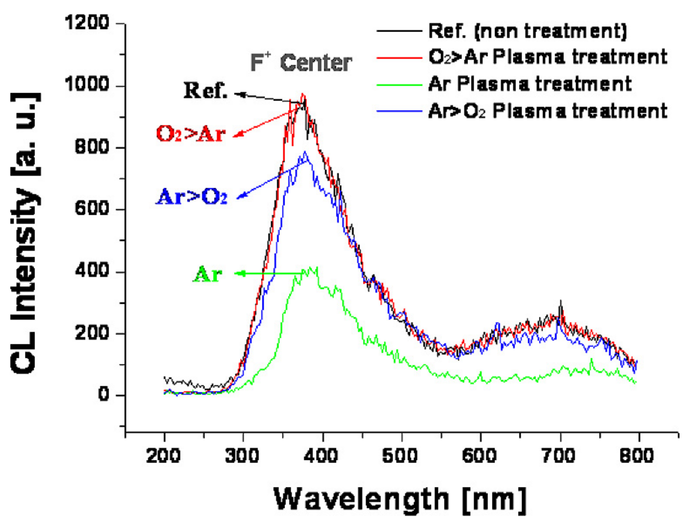


**FIGURE 10** — Comparison of cathodoluminescence spectra of MgO layers measured for a 50-in. full-HD panel with and without RF-plasma pretreatment on the MgO layer under various plasma gases: $O_2$ > Ar, Ar, and Ar > $O_2$.

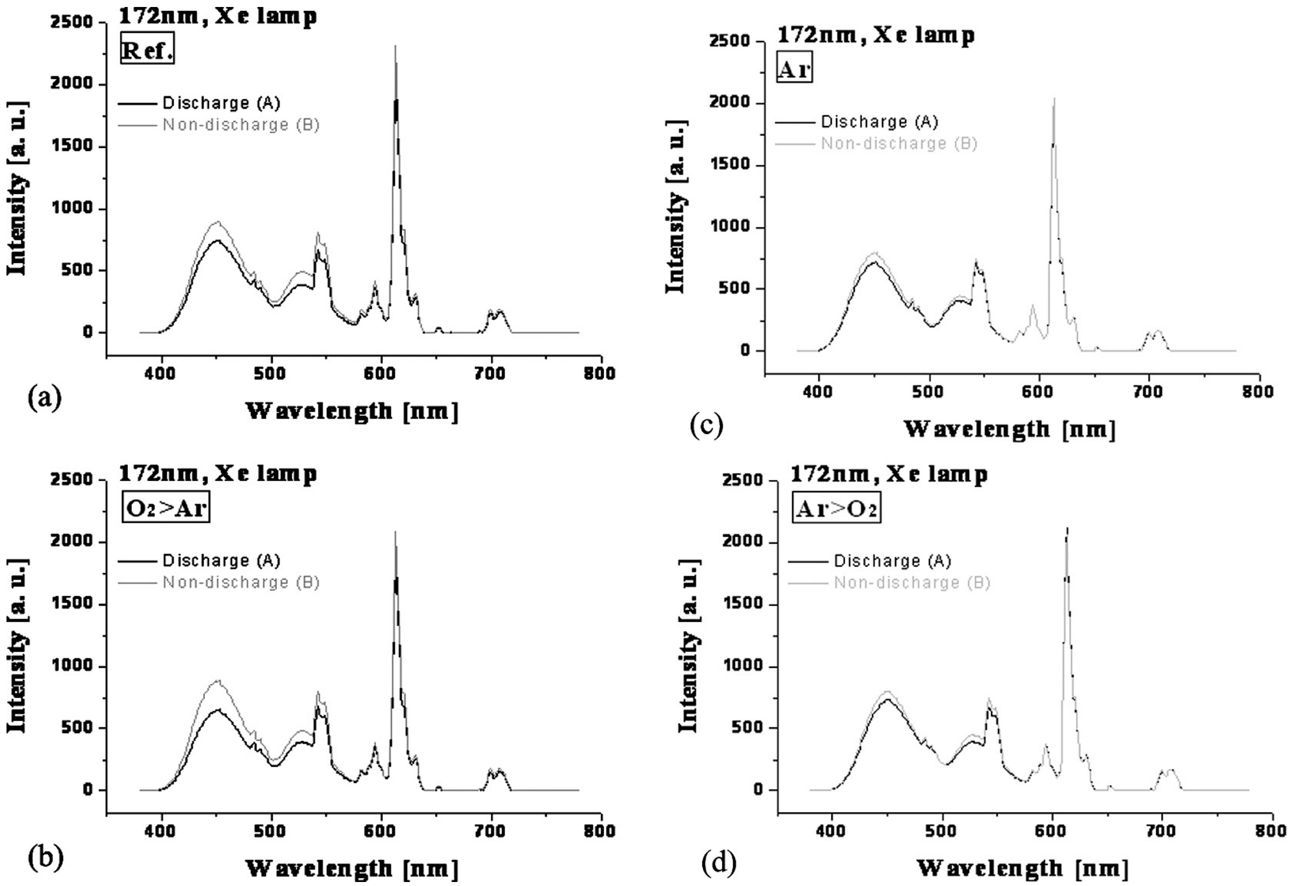


**FIGURE 11** — Comparison of the profiles of the photoluminescence-intensity (172 nm using Xe lamp) changes detected from phosphor layers in discharge (A) and nondischarge (B) regions after 1000 hours of sustain discharge measured for a 50-in. full-HD panel with and without RF-plasma pretreatment on the MgO layer under various plasma gases: $O_2$ > Ar, Ar, and Ar > $O_2$: (a) Ref. panel (without plasma pretreatment), (b) $O_2$ > Ar plasma, (c) Ar plasma, and (d) Ar > $O_2$ plasma.

full-HD panels with and without RF-plasma pretreatment. As shown in Fig. 10, in both cases of Ar and Ar > $O_2$ plasma pretreatments, the $F^+$-center emission peaks of the MgO layers were decreased compared to the panel without plasma pretreatment and $O_2$ > Ar plasma pretreatment. A lower $F^+$-center emission peak means that there are fewer oxygen vacancies. It also means that they are filled by $H^-$ ions, made available from the water in the system or the MgO surface. Consequently, the Ar and Ar > $O_2$ plasma pretreatments on the MgO layer caused a decrease in the $F^+$-center emission peak of the MgO layer, while there is also some indication that it may have increased the MgO surface hardness.

## 4.3 Photoluminescence of phosphor layers

Figure 11 shows the profiles of the photoluminescence (PL) intensity (visible rays, 300–780 nm) emitted from the phosphor layers when irradiated with VUV (172 nm using a Xe lamp) on the surface of the phosphor layers in both discharge (A) and nondischarge (B) regions. In Fig. 11, in both cases of Ar and Ar > $O_2$ plasma pretreatments, the differences in the PL intensity emitted from the phosphor layers between the discharge (A) and nondischarge (B) regions were reduced compared to the panel without the plasma pretreatment (Ref. panel) and $O_2$ > Ar plasma pretreatment. That is for both cases of Ar and Ar > $O_2$ plasma pretreatments, the best permanent image-sticking characteristics on the dark and bright screens were observed, which is due to less obstruction of the visible conversion from VUV by the phosphor layer. As described previously, the Ar or Ar > $O_2$ plasma pretreatment reduced the haze difference on the MgO surface, thus contributing to the suppression of the reduction of the luminance. The Ar or Ar > $O_2$ plasma pretreatment also decreased the sputtering of the MgO and reduced the discharge current for a peak-white pattern by increasing the secondary-electron-emission coefficient of the MgO layer, thus contributing to the suppression of the deposition of the Mg species onto the phosphor layers. This also will help to enhance the lifetime of the MgO layer, including the phosphor layer in current PDP-TVs.

## 5 Conclusion

It is observed that the RF-plasma pretreatment, especially Ar or Ar > $O_2$ plasma pretreatment on a MgO layer, can reduce the permanent image sticking of a 50-in. full-HD ACPDP with a Ne–Xe (11%)–He (35%) content by reducing the sputtering of MgO and decreasing the discharge current for a peak-white pattern. The reduction in the haze difference also suppresses the decrease in luminance. Furthermore, the reduced sputtering of the MgO surface can decrease the deposition of the Mg species onto the phosphor layer. In this case, the visible conversion of the phosphor layer is less degraded even though the strong sustain discharge has been repeatedly produced. Thus, it is expected that these experimental results will help to reduce the permanent image sticking on PDP TVs.


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## References


1 H.-S. Tae *et al.*, "Driving waveform for reducing temporal dark image sticking in AC plasma display panel based on perceived luminance," *IEEE Trans. Plasma Sci.* **34**, No. 3, 996–1003 (June 2006).
2 J.-W. Han *et al.*, "Experimental observation of temperature-dependent characteristics for temporal dark boundary image sticking in 42-in. AC-PDP," *IEEE Trans. Plasma Sci.* **34**, No. 2, 324–330 (Apr. 2006).
3 J. H. Kim *et al.*, "Comparison of temporal dark image sticking produced by face-to-face and coplanar sustain electrode structures," *J. Info. Display* **8**, No. 3, 29–33 (Sept. 2007).
4 C.-S. Park *et al.*, "Reduction of the temporal bright-image sticking in AC-PDP modules using the vacuum sealing method," *J. Info. Display* **9**, No. 4, 39–44 (Dec. 2008).
5 C.-S. Park and H.-S. Tae, "A study on temporal dark image sticking in AC-PDP using vacuum-sealing method," *IEICE Trans. Electron.* **E92-C**, No. 1, 161–165 (Jan. 2009).
6 C.-S. Park *et al.*, "Experimental observation of halo-type boundary image sticking in AC plasma display panel," *IEEE Trans. Electron. Dev.* **54**, No. 6, 1315–1320 (June 2007).
7 C.-S. Park *et al.*, "Recovery of boundary image sticking using aging discharge in AC plasma display panel," *IEEE Trans. Plasma Sci.* **35**, No. 5, 1511–1517 (Oct. 2007).
8 C.-S. Park *et al.*, "Prevention of boundary image sticking in AC plasma display panel using vacuum sealing process," *IEEE Trans. Electron. Dev.* **55**, No. 6, 1345–1351 (June 2008).
9 C.-S. Park and H.-S. Tae, "Solutions to remove a boundary image sticking in an ac plasma display panel," *Appl. Opt.* **48**, No. 25, F76–F81 (Sept. 2009).
10 C.-S. Park *et al.*, "Effect of gas pressure on permanent dark image sticking on bright screen in AC plasma-display panels," *J. Soc. Info. Display* **17**, No. 11, 977–985 (Nov. 2009).
11 N. Nikishin *et al.*, "Role of redeposition of sputtered Mg particles in image sticking," *Proc. IMID '08*, 381–383 (2008).
12 M. J. Jeon *et al.*, "Influence of wall charge on image sticking phenomena in AC plasma display panels," *Displays* **30**, No. 1, 39–43 (Jan. 2009).
13 C.-S. Park *et al.*, "Enhancement of discharge characteristics using RF-plasma treatment on MgO layer in 50-in. Full-HD AC-PDPs," *SID Symposium Digest* **40**, 363–366 (2009).
14 K.-H. Park *et al.*, "Effects of Xe and He contents in ternary gas mixture on luminous efficiency in ac plasma display panel with full-HD cell size," *IEEE Trans. Plasma Sci.* **37**, No. 10, 2061–2067 (Oct. 2009).
15 C.-S. Park *et al.*, "Reduction of the temporal image sticking in AC plasma display panels through the use of high He contents," *J. Info. Display* **10**, No. 4, 195–201 (Dec. 2009).
16 S. H. Lee *et al.*, "Plasma-treatment of MgO film in a.c. plasma display," *Sci. Direct, Surface Coatings Technol.* **171**, No. 1–3, 247–251 (July 2002).
17 W. H. Jeong *et al.*, "Measurement of sputtering yield of the RF-plasma treated MgO films," *Proc. IDW '06*, 1145–1148 (2006).
18 Y. Motoyama *et al.*, "Influence of defect states on the secondary electron emission yield γ from MgO surface," *J. Appl. Phys.* **95**, No. 12, 8419–8424 (June 2004).


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