Mechanism of permanent image sticking induced by ion bombardment and reduction method for ac plasma display panels

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Ion bombardment of the phosphor layer during a sustain discharge was identified as the key factor inducing permanent image sticking and reducing the lifetime of alternating-current (ac) plasma display panels (PDPs). Secondary ion mass spectroscopy (SIMS) confirmed that ion bombardment of the phosphor layer facilitated the re-crystallization of the Mg particles sputtered from the MgO surface during a discharge, thereby degrading the visible conversion of the phosphor layer and eventually lowering the luminance and color temperature. Based on this mechanism, experimental results showed that the re-crystallization of the Mg particles was suppressed when using a positive-biased address electrode to diminish the ion bombardment of the phosphor layer. Consequently, minimizing the ion bombardment of the phosphor layer during a sustain discharge was shown to mitigate permanent image sticking in an ac PDP by suppressing the re-crystallization of the Mg particles. © *2011 American Institute of Physics*. [doi:10.1063/1.3628657]

Permanent image sticking induced by ion bombardment during a long-duration plasma discharge affects the lifetime of current plasma display panels (PDPs) and needs to be improved in order to realize high-quality internet protocol televisions (IPTVs) and smart TVs. While this phenomenon of permanent image sticking is essentially related to deterioration of the MgO surface or phosphor layer during a strong sustain discharge, its detailed mechanism is not yet fully understood. In the discharge region or permanent image sticking region where a strong sustain discharge is repeatedly produced, Mg particles are sputtered from the MgO surface due to the severe bombardment of ions onto the MgO protecting layer, and these sputtered Mg particles are then predominantly deposited on the phosphor layer.[1–5] The resultant degradation of the phosphor layer due to the sputtered Mg particles is thus the major cause of permanent image sticking in current PDPs. However, experiments by the current authors have shown that Mg particles sputtered from the MgO surface do not always induce degradation of the phosphor layer, implying that phosphor degradation only occurs when the sputtered Mg particles are re-crystallized on the phosphor layer. Furthermore, the same experiments also confirmed that the re-crystallization of the sputtered Mg particles on the phosphor layer strongly depended on the deposition of charged Mg particles on the phosphor layer.

Accordingly, this letter discusses the detailed mechanism responsible for inducing permanent image sticking in ac-plasma display panels using three electrodes. An effective method is also proposed to reduce permanent image sticking in PDPs. In particular, to minimize the deposit of charged Mg particles on the phosphor layer and thereby diminish the permanent image sticking phenomenon, a positive-biased voltage is adopted for the address electrode during a sustain discharge.

Figure 1(a) shows a schematic model of the mechanism responsible for inducing permanent image sticking in an ac plasma display panel, where X is the sustain electrode, Y is the scan electrode, and A is the address electrode. Meanwhile, Figs. 1(b) and 1(c) show schematic diagrams of the PDP cells used in the experiment. In Fig. 1(b), the reference cell has a grounded address electrode, which allowed ion bombardment of the phosphor layer during a sustain discharge, whereas in Fig. 1(c), the cell has a positive-biased address electrode (60 V), which prevented ion bombardment of the phosphor layer during a sustain discharge. As shown in Fig. 1, the surface gap between the two parallel electrodes was 60 μm, whereas the plate gap between the address and coplanar electrodes was 125 μm. For the front glass plate shown in Fig. 1, the MgO surface deposited as a protective layer on the dielectric layer was exposed to the discharge space, whereas for the rear glass plate, the phosphor layer was exposed to the discharge space. The total gas pressure was 400 Torr with a Xe-Ne gas mixture (Xe 5%). The microplasma, called the "surface discharge," was produced by applying 180 V to one of the coplanar electrodes, which resulted in heavy ion bombardment of the MgO surface.[1] Thus, varying the potential of the address electrode during the surface discharge can affect the ion bombardment conditions for both the MgO surface and the phosphor layer. When using a grounded electrode, as shown in Fig. 1, the ions produced during a short sustain discharge mainly bombard the MgO surface and partially affect the phosphor layer. Under such bombardment conditions, Mg particles are sputtered from the MgO surface and then mostly re-crystallize on the phosphor layer, which hinders the visible conversion of the phosphor layer.[6] This also lowers the luminance and color temperature, resulting in permanent image sticking and a reduced lifetime for an ac plasma display panel.[2,3]

According to this mechanism, the ion bombardment of the phosphor layer plays a significant role in the re-crystallization of the Mg particles that in turn are responsible for

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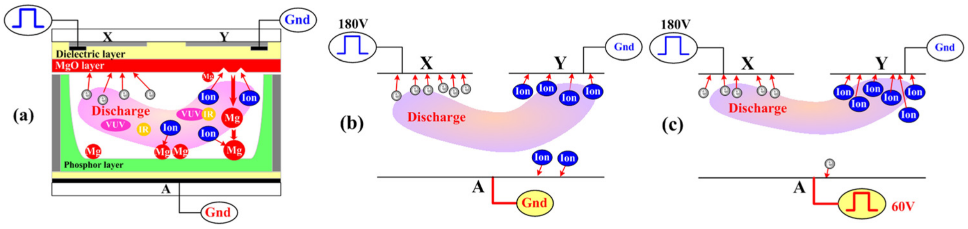

FIG. 1. (Color online) (a) Schematic model describing mechanism of permanent image sticking in ac PDP cell, (b) reference cell with grounded address electrode allowing ions to bombard phosphor layers, and (c) cell with positive-biased address electrode (60 V) preventing ions from bombarding phosphor layers.

damaging the characteristics of the phosphor layer. Consequently, to reduce the ion bombardment of the phosphor layer, the address electrode was positively biased at 60 V during the sustain discharge, as shown in Fig. 1(c). The changes in the MgO surface and phosphor layer induced by varying the ion bombardment conditions were then investigated using atomic force microscope (AFM) and secondary ion mass spectroscopy (SIMS) analyses. AFM was used to monitor the surface roughness based on three-dimensional MgO surface images, while SIMS was used to check the re-crystallization of the Mg particles on the phosphor layer based on Mg intensity images.

The three-dimensional AFM images in Fig. 2 show the MgO surfaces of the non-degraded (a) and degraded regions after a 500-h plasma discharge when using the grounded (=0 V) (b), and positive-biased (=60 V) (c) address electrode during the sustain discharge. The roughness morphology of the MgO surfaces was greater in the degraded regions than in the non-degraded region due to the severe ion bombardment during the plasma discharge.[1,2] However, as shown in Figs. 2(b) and 2(c), the MgO surface with the positive-biased (=60 V) address electrode was more damaged and sputtered than that with the grounded (=0 V) address electrode, implying that more Mg particles were sputtered from the MgO layer due to the intense surface discharge produced by the positive-biased address electrode [not shown here].[7]

Meanwhile, the Mg intensity images in Figure 3 are based on a SIMS analysis of the red phosphor layer in the non-degraded (a) and degraded regions after a 500-h plasma discharge when using the grounded (b), and positive-biased (c) address electrode during the sustain discharge. For the non-discharge region, the dark intensity image in Fig. 3(a) means no Mg particles were detected, implying that no Mg particles were re-crystallized on the phosphor layer. In contrast, when using the grounded address electrode, the bright intensity image in Fig. 3(b) means that a considerable amount of Mg particles was re-crystallized on the phosphor layer. However, when using the positive-biased address electrode, the very weak intensity image in Fig. 3(c) means that very few Mg particles were re-crystallized on the phosphor layer, despite the increased amount of Mg particles sputtered from the MgO surface, as shown in Fig. 2(c). Therefore, the results in Fig. 3(c) confirmed that the re-crystallization of the Mg particles on the phosphor layer was effectively suppressed when blocking the ion bombardment of the phosphor layers using a positive-biased address electrode.

Figure 4 shows the photoluminescent (PL) intensity (visible rays, 380–780 nm) emitted from the phosphor layers when using vacuum ultraviolet (VUV) at a wavelength of 172 nm from a Kr lamp to irradiate the non-degraded and degraded regions after a 500-h plasma discharge when using the grounded and positive-biased address electrode during the sustain discharge. As shown in Fig. 4, with the positive-biased address electrode, the PL intensity emitted from the phosphor layers was less decreased than that with the grounded address electrode. Furthermore, the PL intensity emitted from the red phosphor layer was less affected when compared with that from the green and blue phosphor layers, thereby reducing the color temperature. This lesser degradation characteristic of the red phosphor layer is still unexplained and requires further study.

As a result, the difference in the display luminance and color temperature before and after a 500-h plasma discharge was considerably reduced when using the positive-biased address electrode during the sustain discharge instead of the grounded address electrode, representing a reduction of permanent image sticking (difference in display luminance, ΔL, and color temperature, ΔT, was approximately 75 cd/m^2 and 1456 K with grounded address electrode, respectively, and approximately 56 cd/m^2 and 1168 K with positive-biased address electrode, respectively) [not shown here].[7] When using the positive-biased address electrode, the permanent image sticking characteristics were improved mainly due to less obstruction of the visible conversion and fewer changes to the characteristics of the phosphor layer.

In addition, despite the increased Xe content, the application of a positive-biased address electrode is still expected to help reduce the problem of permanent image sticking in modern PDP panels (>10%) based on blocking the ion bombardment of the phosphor layer during a sustain discharge.[8,9]

In summary, the degradation of the phosphor layer induced by the re-crystallization of Mg particles sputtered from the MgO surface was observed to be strongly related to the ion bombardment of the phosphor layer. When blocking

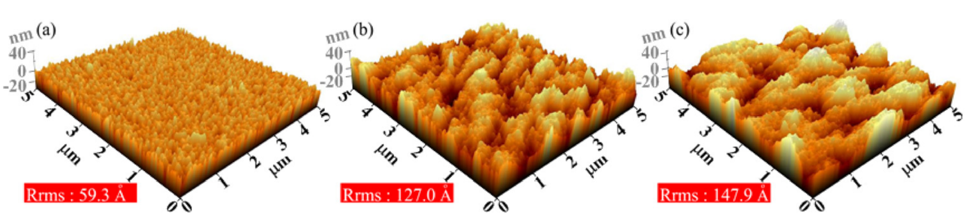

FIG. 2. (Color online) Three-dimensional AFM images of MgO surface roughness: (a) non-degraded region before discharge, (b) degraded region after 500-h sustain discharge with grounded (= 0 V) address electrode, and (c) degraded region after 500-h sustain discharge with positive-biased (= 60 V) address electrode.

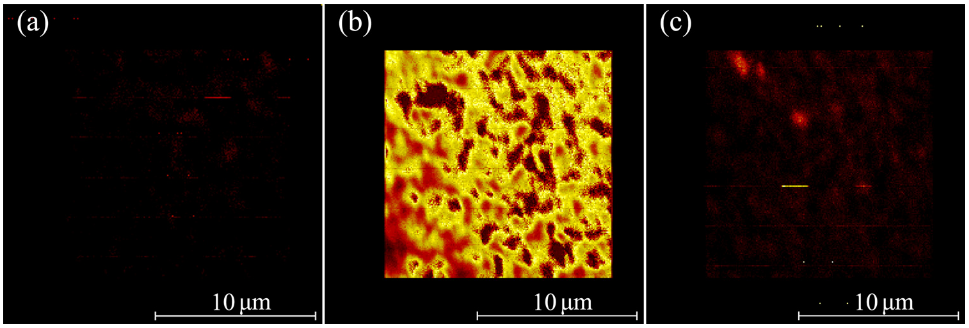

FIG. 3. (Color online) Comparison of Mg intensity images based on SIMS analysis of phosphor layer: (a) no Mg detected in non-degraded region before discharge, (b) intense Mg detected in degraded region after 500-h sustain discharge with grounded (= 0 V) address electrode, and (c) minimal Mg detected in degraded region after 500-h sustain discharge with positive-biased (= 60 V) address electrode.

the ion bombardment of the phosphor layer using a positive-biased address electrode, the re-crystallization of the Mg particles on the phosphor layer was effectively diminished, thereby minimizing the phosphor degradation. It was also confirmed that the positive bias voltage suppressed the deposition of MgO particles, most probably by repelling the charged Mg particles. Therefore, it is expected that these experimental results will help mitigate the problem of phosphor layer degradation and, in so doing, enhance the lifetime of plasma display devices.

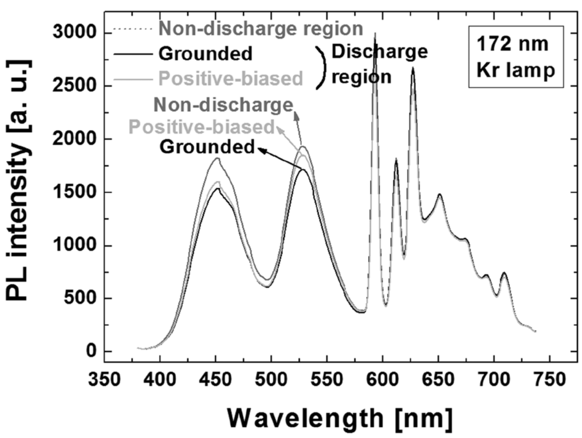

FIG. 4. Comparison of photo intensity (172 nm using Kr lamp) based on PL analysis of phosphor layer before and after 500-h sustain discharge when using grounded (0 V) and positive-biased (60 V) address electrode.

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