Improvement of the Performance and Aging Characteristics of Color Plasma Displays by Using a Co-Evaporated Protecting Layer

(共蒸着保護層を用いたカラープラズマディスプレイの発光特性の改善とエージング特性)

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Abstract This work shows that the application of a MgO and MgF₂ co-evaporated protecting layer to a combination of transmissive and reflective phosphor type color PDPs improves the luminance and the luminous efficiency and the optimum composition of the co-evaporated layers is 24% MgO and 76% MgF₂. This work also confirms that the sustaining voltage and life of reflective phosphor type color PDPs with the co-evaporated protecting layer are almost the same as those with a MgO single protecting layer. The sustaining voltage of combination of transmissive and reflective phosphor type color PDPs, however, is higher than that of reflective phosphor type color PDPs. It is probable that sustaining voltage can be decreased by thinning the thickness of the phosphors.

Key words: ac-PDP, Protecting material, Co-evaporating layer, Combination of transmissive and reflective phosphor type color PDPs, Vacuum ultraviolet rays of 147 nm

1. Introduction

The luminescence from phosphor in color ac PDPs is due to the excitation by vacuum ultraviolet rays of 147 nm from Xe. The latest electrode structure of the surface-discharge ac PDPs applies the reflective type of phosphor layer which is deposited on the barrier ribs and rear substrate as shown in **Fig. 1(a)**. The expansion of the deposited area of phosphors is one of the effective methods to improve luminance and luminous efficiency. It is clear that the concrete method to expand the area is to deposit phosphors on the front substrate as well as rear substrate and barrier ribs as shown in **Fig. 1(b)**.

The deposition of phosphors on the front substrate by using the present technology is carried out the following procedure. First dielectric layer is formed on the front substrate, and then phosphors are deposited. Finally MgO is deposited on the phosphors to prevent from ion sputtering. The deposition of MgO protecting layer on

(a) Reflective phosphor type

(b) Transmissive and reflective phosphor type

The left of (b) is the case of MgO layer.

The right of (b) is the case of transparent materials to 147nm vacuum ultraviolet rays.

Fig. 1 The electrode structure of the surface-discharge ac PDP.

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phosphors, however, does not result in to improve luminance and luminous efficiency, because MgO does not have transparent properties to ultraviolet rays around 147 nm. Accordingly it is important to apply transparent materials to vacuum ultraviolet rays of 147 nm for protecting layer with the electrode structure show in Fig. 1(b). In the present work, we decided to use MgF₂ from the considerations of the transmissivity to 147 nm, value of secondary electron emission yield, γ_i , and the surface potential among MgF₂, LiF, and CaF₂.

It is proved that MgF₂ itself is not able to be applied to protecting layer, because it has weak property against ion sputtering⁶⁾. In order to overcome the difficulty in MgF₂, the double protecting layer was proposed by one of the present authors⁴⁾. The double protecting layer was fabricated by the deposition of MgF₂ with a thickness of 5,000 Å on the phosphors and MgO with a thickness of 400 Å in turn. The application of the double protecting layer to Barrier-Electrode PDPs resulted in achieving the excellent value of 1,030 cd/m² and 1.0 lm/W⁴⁾.

Transmissivity of 147 nm in the double protecting system is 30% even though a thickness of MgO is 400 Å. When MgO protecting layer is thinner than 400 Å, it becomes much weaker against ion sputtering and much shorter life time. Therefore, we decided to apply co-evaporated protecting layer with MgO and MgF₂ in order to have both transmissivity characteristic of MgF₂ and sputtering-proof characteristic of MgO.

2. Experimental

2.1 Co-evaporation method

As shown in Fig. 2, MgO is deposited by electron beam evaporation method and MgF₂ is deposited by heat resistance method, and the total thickness of MgF₂ and MgO is 5,000 Å.

The evaporation velocity of MgO is constant, and the ratio of MgF₂ to MgO is adjusted by changing evaporation velocity of MgF₂.

2.2 Testing panel

Fig. 3 shows the electrode structure of testing panel of PDPs consisting of front substrate with phosphors, and rear substrate with two pairs of sustaining electrodes covered with dielectric layer and co-evaporated protecting layer. On a half of phosphor layer co-evaporated protecting materials is deposited; there is no protecting materials on the other half of phosphor layer. Luminance of co-evaporated protecting layer on phosphor layer and that of no protecting layer are measured and

Fig. 2 Film deposition method by co-evaporation.

Fig. 3 Electrode structure of testing panel.

compared. Luminance and luminous efficiency were measured in the demountable tube under the condition of 4.0×10^{-4} Pa Penning mixture gas of Ne+Xe (4.0%). Before the measurements testing panels were heated for 6 hours at the temperature of 350°C under the vacuum condition of 7.0×10^{-6} Pa.

3. Results and Discussions

Ion induced secondary electron emission yield, γ_i is defined as value for secondary electron current divided by incident ion current. Fig. 4 shows the relationships between γ_i and the composite ratio of co-evaporated layer. The composite ratio of co-evaporated layer was confirmed by the measurement of Rutherford Back scattering Spectroscopy (RBS). As shown in Fig. 4(a), a value of γ_i is a maximum at the composite ratio of MgO to MgF₂ of 23%. The surface potential is defined as a value of the voltage which corresponds to the

(a) Relationship between γ_i and the composite ratio of MgO

(b) Relationship between γ_i and collector voltage

Fig. 4 Characteristics of γ_i .

Fig. 5 The equivalent circuits of a PDP cell.

(a) Relationship between luminance and composite ratio of MgO

(b) Relationship between memory margin and composite ratio of MgO

Fig. 6 Relationships between luminance and memory margin, and composite ratio of MgO.

saturated point in the characteristic curve of γ_i versus collector voltage⁵⁾. As shown in Fig. 4(b), the surface potential of co-evaporated layer is lower than that of MgO single layer by 85 V.

When resistance of dielectric material is high, the surface potential is able to be maintained to be high due to the ion bombardment and also the capability to accumulate wall charge is large during ac operation of PDPs. From the equivalent circuits shown in Fig. 5, the relationships among the sustaining voltage, V_s , the cell voltage, V_c , and the wall voltage, V_w , are defined as $V_c = kV_s + V_w$, where $k = C_o / (C_o + 2C_c)$. C_o and C_c are equivalent capacitance of dielectric layer and that of space, respectively. From these relationships V_w should be increased to make the sustaining voltage, V_s , low. Therefore, the capability to accumulate wall charge is dominant factor whether PDPs are able to be operated by low V_s and wide memory margin or not.

From the difference of luminance between co-evaporated protecting layer on phosphor layer and no protecting layer, the relationships between the luminance and the composite ratio of MgO in co-evaporated protecting layer is shown in Fig. 6(a). Luminance decreases as the composite ratio of MgO increases. Fig.

6(b) shows the relationships between memory margin and the composite ratio of MgO in co-evaporated protecting layer. Memory margin increases as the composite ratio of MgO increases because minimum sustaining voltage decrease as the composite ratio of MgO increases. Memory margin of MgO single protecting layer is larger than that of MgF₂ single protecting layer by 3 V.

Memory margin is defined as the difference between the maximum sustaining voltage and minimum one and desired as large as possible in order to be operated without misaddressing in the whole display area. In the present paper the optimum composite ratio of MgO and MgF₂ is obtained from cross point in Fig. 7 where Fig. 6(a) and 6(b) are combined. From Fig. 7, it is clear that the optimum composite ratio of MgO to co-evaporated layer is 24%.

Fig. 7 Relationships between normalized luminance and memory margin, and composite ratio of MgO.

By application of co-evaporation materials to protecting layer it is expected that luminance may increase 2.8 times and memory margin may decrease by 1.5 V with compared to MgO single protecting layer. Total luminance is estimated to be 950 cd/m² because of luminance of 350 cd/m² from front substrate and that of 600 cd/m² from rear substrate. For *R* type PDPs (see appendix), a value of the measured luminance from rear substrate is 800 cd/m². Transmissivity of visible light through phosphor layer with a thickness of 10 μm is 75%. For *T+R* type PDPs, a luminance from rear substrate is 800 × 0.75 = 600 cd/m². The co-evaporated protecting layer is efficient to improvement of luminance for ac-PDPs.

Fig. 8 shows the aging characteristics for *R* type PDPs whose composite ratio of MgO is 24%, 100% and *T+R* type PDPs whose composite ratio of MgO is 24% in the demountable tube, respectively. V_s is also defined as $(V_f + V_{sm})/2$, where V_f and V_{sm} are minimum firing voltage and minimum sustaining voltage, respectively. The exact life time for the present materials should be confirmed by measuring chipped-off PDPs. For convenience to evaluate a lot of protecting materials whether they are suitable or not from the point of view of a life time, we introduced a temporary life-time measurement system to operate for 500 minutes in the demountable measuring apparatus to compared with the MgO sample deposited by vacuum evaporated as a standard. It is sure that co-evaporated protecting layer in the composite ratio of MgO to MgF₂ of 24% is the same life time as MgO single protecting layer.

Sustaining voltage of co-evaporated protecting layer is higher than that of MgO single protecting layer by 10 V. Sustaining voltage of *T+R* type PDPs is higher than

Fig. 8 Aging Characteristics of sustaining voltage at MgO composite ratio of 24% and 100%.

Fig. 9 Luminous efficiency of *T+R* and *R* types at MgO composite ratio of 24% and 100%.

that of *R* type PDPs by 100 V. A value of γ_i of co-evaporated layer is larger than that of MgO layer. The surface potential of co-evaporated layer, however, is smaller than that of MgO layer. Experimental results concerning wall voltage show the tendency that the degree of decrease in V_s due to a large value of γ_i is smaller than that of decrease in V_s due to the increase in wall charge, and vice versa.

It is suggested that the decrease of V_s in *T+R* type PDPs is caused by two reasons. When phosphor layer is inserted between dielectric layer and protecting layer, a value of C_o shown in Fig. 5 decreases. The first one is that decrease of C_o results in increases of V_s ; the second one is that a value of γ_i is supposed to be lowered for surface of phosphor layer, because the surface of the protecting layer is very unevenness due to the complicated shape of phosphor. It is well known that the secondary electron emission from rough surface is lowered due to preventing the secondary electrons from escaping out of the surface.

Fig. 9 shows Luminous efficiency for the same PDPs as Fig. 8. Luminous efficiency of *T+R* type PDPs is 0.33 lm/W. That of *R* type PDPs is 0.22 lm/W. Accordingly, luminous efficiency of *T+R* type PDPs is 1.5 times comparing with that of *R* type PDPs. From this result, it is expect that the real PDPs may have luminous efficiency of 1.5 times, too.

Fig. 10 shows the THEED (Transmission High Energy Electron Diffraction) pattern of co-evaporated layer whose composite ratio of MgO to MgF₂ is 24%. This result indicates that the present co-evaporated material is polycrystal because many rings are observed in the THEED pattern. Calculating from the radius of rings in the THEED pattern, values of the interplanar

Fig. 10 THEED pattern of co-evaporated layer.

Fig. 11 Phase equilibrium diagram of the binary system MgO-MgF₂.

spacing are 3.122 Å, 2.491 Å, 2.230 Å, 2.054 Å, 1.697 Å, 1.437 Å, 1.361 Å, 1.207 Å and 1.110 Å in order from inside ring, respectively. From the analyses of them by JCPDS card, it is proved that these interplanar spacings correspond to MgF₂(110), MgO(111), MgF₂(111), MgF₂(210), MgF₂(211), MgO(220), MgF₂(301), MgO(222) and MgF₂(222) in order from inside ring, respectively. The crystal structure of MgO and MgF₂ are the rock-salt structure and TiO₂ (rutile) structure, respectively. The observed results of the THEED suggest that the present co-evaporated material has a state of eutectic mixture.

Phase equilibrium diagram of the binary system MgO-MgF₂ is shown in Fig. 11, where is a state of eutectic mixture of MgO and MgF₂, but no state of solid solution⁷⁾. Fig. 11 supports our explanation to the THEED of the co-evaporated MgO and MgF₂ described above.

4. Conclusion

We measured luminance and aging characteristics for several kinds of composition ratios of co-evaporated layer. The optimum composite ratio of MgO and MgF₂ to co-evaporated layer is 24% and 76%, respectively. It is sure that co-evaporated protecting layer in the composite ratio of MgO to MgF₂ of 24% is the same life time as MgO single protecting layer. Sustaining voltage of *T* + *R* type PDPs is higher than that of *R* type PDPs by 100 V by depositing phosphors on the front substrate. Luminous efficiency of *T* + *R* type PDPs is 1.5 times comparing with that of *R* type PDPs.

The present co-evaporated protecting layer has a state of eutectic mixture. In this work, a thickness of phosphors on the front substrate is 10 μm. It is expected that sustaining voltage is decreased by thinning a thickness of phosphor layer and flattening phosphor layer. It is requested to use small size phosphors on the front substrate.

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APPENDIX

In Fig. 12, the structure of the left is "*T* type PDPs" and that of the center is "*R* type PDPs". We define that of the right as "*T* + *R* type PDPs" as shown in this figure.

Fig. 12 Construction of the phosphor layer in a cell of color PDPs.

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