Experiments and Numerical Analyses of Charged Particle's Behavior in a Plasma Display Panel

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Experimental and numerical studies of erosion process of an MgO layer were performed in order to obtain a fundamental guideline for lifetime evaluation of a plasma display panel (PDP). From the experimental results of an over-voltage accelerated discharge test and surface analysis of the MgO layer, it was found that the erosion and deterioration progressed due to the bombarding ions and adsorbed impurities, respectively, in the MgO surface during the accelerated discharge. The numerical analysis of the plasma behavior and its structure in PDP discharge was performed to explain these experimental results. The localized erosion on the MgO surface was due to the discontinuity of the ion bombardment, which was further expedited by the charge accumulated in dielectric (wall charge) behavior. The combination of these behaviors of charge particle was found to explain the localized erosion process in the MgO layer in the accelerated PDP discharge.

Keywords : plasma display panel, MgO, erosion

1. Introduction

The technological advances of the plasma display panel (PDP) have triggered considerable interests in the fields of large-size, high-brightness flat panel displays and high definition television (HDTV). Research and development of PDP technology have been remarkable; however, more studies are still required to enhance the luminous efficiency, lifetime and power consumption⁽¹⁾⁻⁽⁴⁾. It has been well known that the MgO layer (about 500 nm) is deposited on the dielectric surface above the coplanar electrodes to protect the dielectric from sputtering and to provide large secondary electron emission under ion impact⁽⁵⁾. Erosion of the MgO layer is one of the important problems that must be studied. The method of judging longevity with reliability in the PDP discharge is not clarified enough.

It is necessary to obtain a guideline for the lifetime evaluation of a PDP discharge. In order to clarify the erosion process of the MgO layer in a PDP discharge, investigations on MgO surface erosion were performed both experimentally and numerically based on reliable and quantitative analysis. We also observed the characteristics of the surface erosion of the MgO layer and thus investigated the experimental results by a numerical simulation for plasma behavior and its structure under the experimental conditions. Based on the experimental and numerical investigations, the relationship between these plasma characteristics and the erosion process of the MgO layer in the accelerated discharge were discussed.

2. Experiments

A test panel was prepared by assembling the rear and front panel without sealing. The panel was installed into the test

chamber as shown in Fig. 1. The chamber was exhausted to 10^{-6} Torr by a rotary pump and a turbo molecular pump (TMP). Working gas mixture was poured into the chamber and then the valve of the chamber was closed to sustain pressure. All cells of the test panel were initially operated in the aging process for 1 hour and the old gas mixture was replaced with the new one. Before starting accelerated discharge test, the test panel was applied by a low frequency pulse voltage so as not to be stressed.

The main conditions of the present lifetime test of MgO layer were summarized as follows: (1) accelerating frequency was 50 kHz, (2) initial mean discharge voltage was set at 240 V (firing voltage V_f : 300 V, sustaining voltage V_s : 180 V), and (3) gas pressure of Ne-Xe (5 %) was 200 Torr. In order to confirm these surface changes in the MgO layer, observations of the surface structure of the MgO layer were performed using x-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM).

Figure 2 shows the SEM photographs of the MgO surface after the accelerated lifetime test and side view for the observation position of the sample. Table 1 shows a specification of the test panel. The SEM observations of the MgO surface were mainly

Fig. 1. Experimental setup

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performed at two positions: gap edge (A) and outer side (B) regions as shown in Fig. 2(a). When the observation position moved from position B to A, it could be seen that the relatively smooth surface became rough as the erosion increased. Also, the erosion pattern was most remarkable in position A. It could be seen from Fig. 2 that the erosion patterns of the MgO surface became spatially non-uniform and most eroded region existed near the edge side of the MgO surface layer.

The XPS wide spectrum of the MgO film is shown in Fig. 3. Table 2 also shows the spectral features for each element obtained

Fig. 2. The SEM photographs of eroded MgO surface

Table 1. Specification of the test panel

Thickness of MgO film	0.5 μm
Thickness of dielectric layer	25.5 μm
Width of electrode	380 μm
Electrode gap	80 μm
Pixel pitch	1200 μm

Fig. 3. XPS wide spectra of the eroded MgO film at the position A

from the results of XPS analyses. The Mg (2s) peak at $E_b=91 \pm 1.5$ eV and oxygen (O1s) peak at $E_b=533 \pm 2$ eV corresponded to Mg and oxygen atoms incorporated in the MgO surface layer, respectively. An additional peak of C (1s) on the top of the surface, which is a peculiarity of XPS analysis, was also detected at the binding energy of about 290 eV. It is found, from the results of the XPS spectral profiles for each element, that the concentration ratio (%) for Mg and O in the position A was almost the same (44:42), while it was not equal in position B. Also, the small amount of the impurity elements such as carbon and Pb were also detected partially in the B region. It is presumed that these impurities, which were sputtered from the dielectric wall, were adsorbed on the MgO surface during discharge.

Figure 4 shows the non-uniformity of the concentration ratio (%) of Mg and O elements. The non-uniformity here was defined as the absolute value for the difference of Mg and O with respect to the concentration ratio of each element ($|\text{Mg}(\%) - \text{O}(\%)|$). We believe that the observed values shown in Fig. 4 represent the deterioration degree of MgO surface layer. The value of the non-uniformity is also increased with the deterioration. For the non-uniformity calculations of analyzed Mg and O elements, we first obtained the average profile from the five times measured profiles, and then, we calculated the non-uniformity using the relation already defined. As shown in Fig. 4, the non-uniformity was the maximum (about 10%) at $x=500\mu\text{m}$ (around position B), while the value remains less than 4 % at the positions of $x= 50$ and $100 \mu\text{m}$ (around position A). These SEM and XPS results suggest that the deterioration progressed by the sputtered impurities in the position B, while the erosion occurred dominantly in the position A. This also indicated that the energetic particle bombardment plays a role not only in the erosion but also in the surface cleaning. Since the localized erosion in the MgO layer was caused by the plasma structure and behavior in the discharge, correlations were investigated in the following section.

Fig. 4. Non-uniformity of the concentration ratio (%)

Table 2. Results of XPS analysis for MgO surface around position A

Element	Binding E (eV)	Peak Width (eV)	Peak Area (cts-eV/s)	Sensitivity Factor	Concentration Ratio (%)
Mg (2s)	91.2	2.8	9883	0.639	44.1
O (1s)	533.4	2.7	36253	2.494	42.4
C (1s)	289.6	...	5059	1	13.5

3. Simulation

The discharge cell was modeled reasonably in two dimensions as shown in Fig. 5. It was, however, noted that the front glass plate, the rear glass plate, and the dielectric rib were ignored in the model. The periodic boundary condition was assumed at both ends of the cell in the x direction. The applied voltages were 240 V and 120 V for the left sustain and address electrodes, respectively, against the right sustain electrode which was set to 0 V. The pressure was 200 Torr. The gas composition was Ne (95%) and Xe (5%). The OOPIC (object oriented particle in cell) code⁽⁶⁾⁽⁷⁾ as a kinetic simulator was modified and carried out in order to simulate our accelerated PDP discharge. The coordinate space and the velocity space of this simulator are two-dimensional and three-dimensional, respectively. The simulation conditions were as follows: the initial densities were $10^{16}/\text{m}^3$ for electrons and ions. The number of grids is 60 for the x direction and 42 for the y direction. The time step is fixed to 10^{-13} sec to satisfy the Courant-Friedrichs-Lewy condition. The secondary emission coefficients of the dielectric surface are 0.5 for Ne ions and 0.05 for Xe ions in the simulation. The Monte Carlo collision method was used for the electron-neutral, ion-neutral collisions in kinetic simulation. The discharge includes electron-neutral elastic, excitation, and ionization collisions, as well as ion-neutral charge-exchange collisions.

Figure 6 shows the examples of the calculated results for the temporal and spatial distribution of Xe ions during a half-period pulse discharge. The discharges were calculated at 1.6×10^{-8} , 1.6×10^{-7} , and 1.6×10^{-6} sec, respectively. The half-period of 300 kHz pulse discharge was corresponded to the discharge time of about 1.65×10^{-6} sec.

In the calculations, the plasma behaviors can be distinguished with three main time domains, such as initial discharge ($\sim 10^{-8}$ sec), plasma expansion ($\sim 10^{-7}$ sec) and saturation and diffusion of the plasma ($\sim 10^{-6}$ sec). In the stage of initial discharge, the plasma forms above the MgO surface around the gap region of the electrode (Fig. 6(a)). With increase of densities, the plasma expands to outer side of the cathode electrode in the plasma expansion stage (Fig. 6(b)). The plasma expansion toward the anode side is advanced speedily while forming the striation distribution in Xe ions. Finally, the density of bulk ions, which are formed spatially in the cathode side, is saturated and decreases gradually while the bulk ions near the anode side propagates

Fig. 5. Discharge cell configuration used in 2-D simulations

(a) 1.6×10^{-8} sec

(b) 1.6×10^{-7} sec

(c) 1.6×10^{-6} sec

Fig. 6. Spatial distribution of Xe ions

toward the outer side of anode and diffuses broadly (Fig. 6(c)). Since the loss and production of plasma are balanced under a steady state condition in these saturation and diffusion stage, the plasma generation is saturated. The discharge is dominantly dependent on Xe ions, whereas Ne ions with comparatively high ionization energy are gradually decreased. It is seen, from the results of Fig. 6 that the plasma production has almost reached to the steady state during the discharge condition of 300 kHz.

Figure 7 shows the examples of the calculated results for the electric field strength distribution during a half-period pulse discharge. As shown in Fig. 7(a), the calculated electric field strength has a peak around the gap region of the sustain electrode. The ion gains energy from the high electric field near the edge side of cathode, and the kinetic energy of the incident ion on the MgO surface are increased. This indicates that ion bombardment in the high electric field region is spatially concentrated on the inner edge side of both electrodes during the discharge. Therefore, this intensive electric field distribution near the gap region causes the localized erosion of the MgO layer.

Figure 8 shows the calculated results for the surface wall charge due to the electrons, Xe and Ne ions incident on the MgO surface. From the result of calculated wall charge profiles on the MgO surface during the discharge, it can be found that the positive wall charge by the ions and negative wall charge by the electrons gradually increase on the right cathode and left anode sides, respectively. This implies that the wall potential of the right cathode side increases, while that of anode side decreases. It was reported that the wall potential is almost saturated with about half of sustain voltage⁽⁸⁾. Therefore, it can be seen that the wall charge behavior plays a role to hold down the bombardment of high-energy ions in the steady state. In addition, from the calculated results, the ions with high-energies (>100 eV) are bombarded locally on the edge side of the cathode at the initial discharge stage. With increase of wall potential and collisions, kinetic energies of the bombarding ions are also decreased by dozens of electron volts at maximum, although the bombarding region is spread from the inner edge side to the all cathode surface with diffusion of the plasma. Therefore, the ion bombardment with high-energies is limited spatially and temporally near the inner edge side of both electrodes during the initial discharge stage. This discontinuous ion bombardment also causes the localization of the erosion of the MgO surface layer.

In our calculation, the threshold voltages of sputter (V_T) and mean sputter yields (S_{av}) of MgO were set as 25 V, 2×10^{-3} for sputtering by Ne ion and 95 V, 1×10^{-4} for Xe ion, in consideration of the recent theoretical report⁽⁹⁾. Erosion calculations were also made using y component of the kinetic ion energies (E_y) because of the assumption that the erosion mainly depends on the energy of y direction to the MgO surface. Once the sputter yield ($S(E)$) of the bombarding ions and the energy distribution (E_y) of Xe and Ne fluxes are obtained, the erosion rate (R) of MgO is calculated by

$$R = \int_0^{V_s} S(E) \cdot E_y(E) dE \quad \dots\dots\dots (1)$$

where V_s is the sheath fall potential of MgO surface layer. As shown in Fig. 9, the profiles of the erosion have peaks around the inner edge region of the cathode during the discharge because of the discontinuity of the ion bombardment as previously mentioned. The discharge also showed a tendency to be dominantly depended on the Xe ions with comparatively low ionization and high

Fig. 7. Spatial distribution of the electric field strength

 (a) 1.6×10^{-8} sec

 (b) 1.6×10^{-7} sec

 (c) 1.6×10^{-6} sec

 Fig. 8. Number density of surface charge of electron, Xe^+ , Ne^+ on the MgO surface

Fig. 9. Normalized erosion distributions in the MgO surface

threshold sputter energy, whereas the Ne ions with high ionization and low threshold energy gradually disappeared in the steady state of the plasma production. Therefore, we believe that the erosion region does not further expand and localized near the edge side of the MgO surface due to these combinational factors, which reflected the experimental results in Sec. 2. The experimental trends are explained with the above-calculated results, and are summarized as follows. First, the erosion distribution depends mainly on the behaviors of bombardment ions and wall charge accumulated on the MgO surface layer. Second, the erosion region on the MgO surface is localized because by the non-uniformity of the ion bombardment. Besides, the deterioration with impurities progresses in the other surface region during the discharge. Finally, the main discharge is concentrated around this erosion region.

4. Conclusion

In order to obtain a fundamental guideline for the evaluation of the lifetime of a PDP, erosion process of the MgO layer was experimentally examined using over-voltage accelerated discharge test and surface analyses. The results showed that the erosion and deterioration with adsorbed impurities progressed simultaneously in the MgO surface in the accelerated discharge. The erosion region was also localized around the inner edge side of the electrode while the deterioration dominantly occurred in the other region of the MgO surface. The numerical investigation was performed using the computer simulation that analyzed the plasma behavior and structure in PDP discharge to explain the experimental results. The result showed that the electric field strength has a peak around the gap region of the sustain electrode. The ion bombarding in the high electric field region is spatially concentrated on the inner edge side of both electrodes during the discharge. Therefore, this intensive electric field distribution near the gap region causes the localized erosion of the MgO layer. Furthermore, the erosion distribution depends mainly on the behaviors of bombardment ions and wall charge accumulated on the MgO surface layer. Thus, the erosion region is localized because of the non-uniformity of the ion bombardment. However, it is necessary to obtain the direct measured data for the MgO erosion, such as the sputter phenomenon and sputter rate in a real

PDP discharge, in order to obtain a guideline for the evaluation of the lifetime of a PDP discharge. Further research is in progress, in particular taking the measured Mg particles behavior sputtered from the MgO layer during the discharge into account.

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References

- (1) K. Tachibana and S. Feng : "Spatiotemporal behaviors of excited Xe atoms in unit discharge cell of ac-type plasma display panel studied by laser spectroscopic microscopy", *J. Appl. Phys.*, Vol.88, pp. 4967-4974 (2000)
- (2) H. Uchiike : "Review of plasma display panel", *T. IEE Japan.*, Vol.116, No.8, pp. 503-507 (1996) (in Japanese)
- (3) Th. Callegari, R. Ganter, and J. P. Boeuf : "Diagnostics and modeling of a macroscopic plasma display panel cell", *J. Appl. Phys.*, Vol.88, pp. 3905-3913 (2000)
- (4) C. H. Park, S. H. Lee, D. H. Kim, Y. K. Kim, and J. H. Shin : "A Study on the New Type Sustaining Electrode Showing High Luminous Efficiency in AC PDPs", *IEEE Trans. Electron Devices*, Vol.48, pp. 2255-2259 (2001)
- (5) C. H. Park, Y. K. Kim, S. H. Lee, W. G. Lee, and Y. M. Sung : "Surface-discharge characteristics of MgO-thin films prepared by reactive RF unbalanced magnetron sputtering", *Thin Solid Films*, Vol.366, pp. 88-94 (2000)
- (6) C. H. Shon and J. K. Lee : "Striation phenomenon in the plasma display panel", *Phys. Plasmas*, Vol.8, pp. 1070-1080 (2001)
- (7) J. P. Verboncoeur and D. Cooperberg : "Electromagnetic PIC modeling with a background gas", *AIP Conference Proceedings*, Vol.391, pp. 83-88 (1997)
- (8) Y. Ikeda, K. Suzuki, H. Fukumoto, J. P. Verboncoeur, P. J. Christenson, C. K. Birdsall, M. Shibata, and M. Ishigaki : "Two-dimensional particle simulation of a sustained discharge in an alternating current plasma display panel", *J. Appl. Phys.*, Vol.88, pp. 6216-6223 (2000)
- (9) S. J. Yoon and I. S. Lee : "Theory of the lifetime of the MgO protecting layer in ac plasma display panels", *J. Appl. Phys.*, Vol.91, pp. 2487-2492 (2002)

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