Application of Optical Method for Quantitative Investigation of MgO Erosion in AC-PDP

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Abstract

For the quantitative investigation of the erosion of MgO layers in real ac-PDP cells, we constructed a microscopic spectrophotometer which is capable of measuring transmission spectra from the area as small as 20 × 20 μm². In the test on the sputtered MgO films with a thickness gradient, we were able to probe the thickness variation of 1000 nm over 1000-μm distance. Using this instrument, we were able to determine not only the erosion rate at the particular position of ac-PDP cells but also the relative erosion rate at different positions in a single ac-PDP cell.

Introduction

In the ac plasma display panels (ac-PDPs), the MgO layers play the dual role of the protective layer for dielectric layers and the secondary electron supplier due to their high sputtering thresholds and high secondary electron emission coefficients, respectively. Therefore, operational longevity of the ac-PDPs critically depends on the long-term stability of the MgO layers. However, the MgO layers, which are in direct contact with the plasma, are inevitably bombarded by ions, and their erosion causes the eventual failures of ac-PDPs.

Considering the importance of MgO layers in the operation of ac-PDPs, the scarcity of studies on erosion of MgO layers in real PDP cells is rather surprising. Few previous reports on the modification of MgO layers in PDPs due to ion bombardment relied mostly on scanning electron microscopy (SEM), and consequently were unable to determine erosion rate quantitatively.

Stylus profilometry and spectrophotometry are the two popular methods to determine the thickness of thin films. However, the applicability of stylus method for the quantitative measurement of the MgO erosion in real ac-PDPs is somewhat limited due to the lack of proper baseline. Moreover, stylus method is intrinsically an ex-situ measurement technique; to use stylus method, the front and back glass plates have to be separated. Unlike stylus method, spectrophotometry does not require baseline for the thickness determination. Also, spectrophotometry has the potential for the in-situ measurement due to its non-destructive and non-invasive nature. However, conventional spectrometer is unsuitable for probing the tiny ac-PDP cells, and therefore, we constructed a novel microscopic spectrophotometer.

Experimental

ac-PDPs examined in this study were three-electrode type with 350-μm-wide ITO sustaining-electrodes. The gap between ITO electrodes was 50 μm. MgO layer of ~500 nm were deposited on top of 30-μm-thick dielectric layers by e-beam evaporation, and the mixture of He, Ne, and Xe was used as a discharge gas. ac-PDPs operation was carried out at the sustaining voltage of ~180 V.

The homemade microscopic spectrophotometer consists of a tungsten lamp, a microscope system, a CCD camera, and an array-type detector. Adjusting the slit width, measurement area can be reduced to a few square μm. Nevertheless, due to the limit in the light-source intensity and the detector sensitivity, 20 × 20 μm² is the practical limit of measurement area in the current setup.

Result and Discussion

Fig. 1 shows the typical SEM image of ac-PDPs after 1000-hour operation. This figure clearly shows the evidence for the erosion of MgO layers. Moreover, the variation in the contrast reveals that the erosion of MgO layers is not uniform; note the signature of more severe erosion near the edges of the ITO electrodes. The non-uniform erosion of MgO layers was more clearly revealed by α-step measurement shown in Fig. 2. In particular, the comparison of the surface profiles of the 9- and the 1000-hour-operated samples demonstrates that the prolonged operation results in more pronounced non-uniform erosion. It is conceivable that the field enhancement near ITO electrode edges was responsible for the severe erosion in these regions.

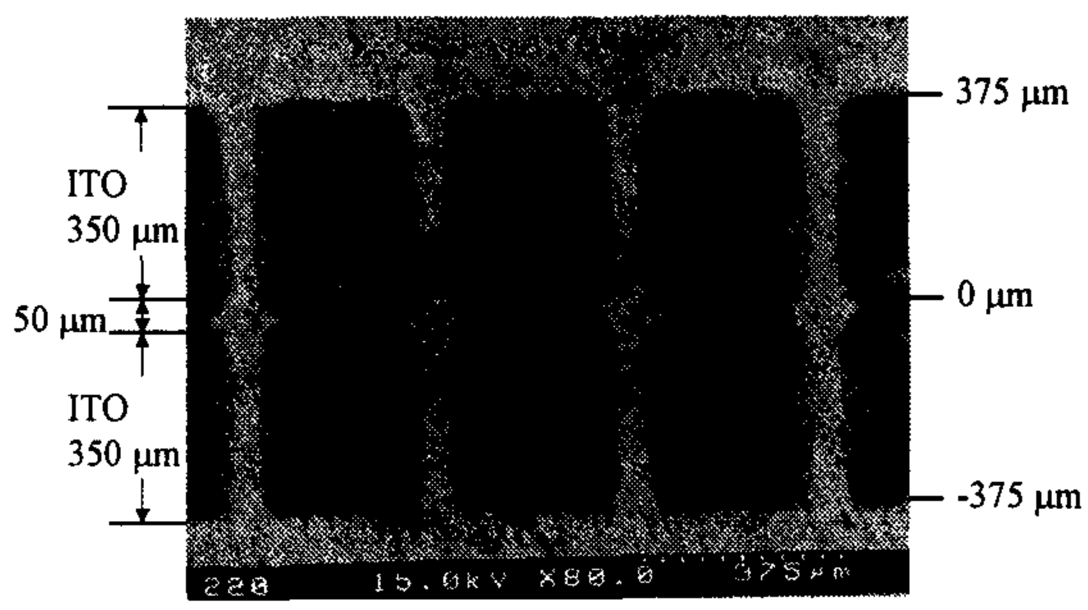

Fig. 1 Typical SEM image of ac-PDPs after 1000-hour operation.

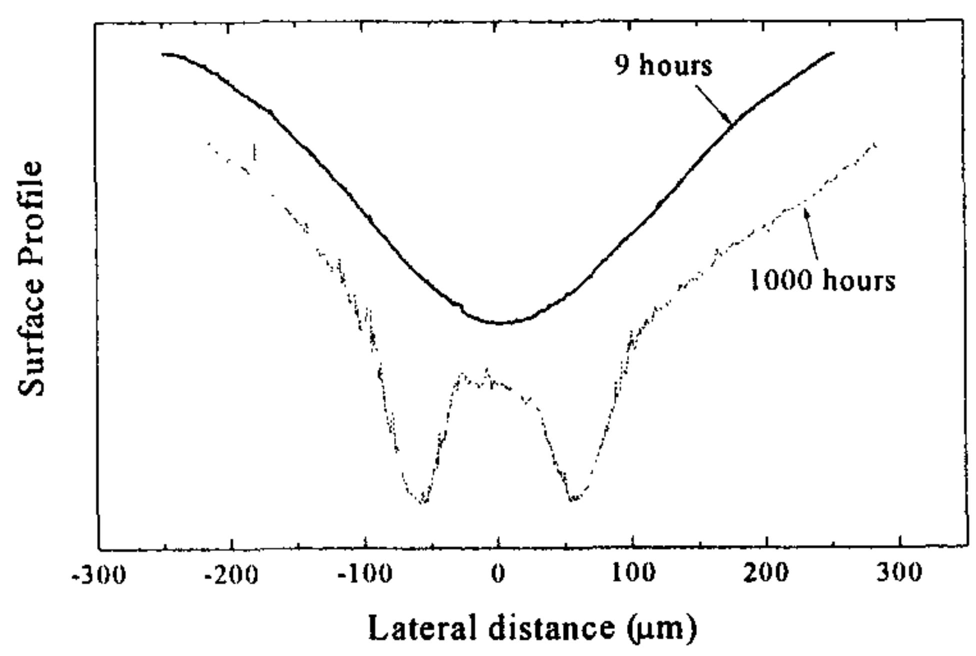

Fig. 2 Comparison of the surface profiles of ac-PDPs. operated for 9 and 1000 hours.

As already mentioned, the quantification of erosion from α-step measurement is not straightforward due to the lack of proper baseline. Therefore, we cannot directly compare the extent of erosion between two samples from Fig. 2; the curve for 9-hour operation is arbitrary positioned relative to that of 1000-hour operation. However, the lateral-position-dependent variation (lateral position is marked in Fig. 1) of the MgO thickness is well represented by α-step measurement.

Since the failure of ac-PDP is most likely to occur in the severely eroded regions (around ±50 μm in Fig. 2), the investigation of the local erosion rate (or the variation of the actual MgO layer thickness) in these regions is sufficient to estimate the lifetime of ac-PDP. However, the mapping of the MgO layer thickness in a single cell is more interesting because valuable information on the plasma discharge in tiny PDP-cells can be deduced.

To test the thickness mapping capability of the homemade microscopic spectrophotometer, we prepared a MgO film with thickness gradient on a glass substrate by RF sputtering; α-step measurement showed thickness variation of 1000 nm over 1000-μm distance. We measured transmission spectra in the distance-interval of 100 μm. The distance of the measurement positions were measured from the reference point corresponding to the thickness of 1400 nm (see inset of Fig. 3).

Since transmission maximum occurs when $4\pi nd = m\lambda$ (n is refractive index, d is thickness, m is the order of the maximum, and λ is wavelength) from the interference condition, the shift of the transmission maximum of the same order to shorter wavelength can be attributed to the reduction of thickness. More specifically, the shift of the transmission maximum of the same order can be used to estimate the relative thickness difference when the wavelength-dependent variation of the refractive index is not significant: $(\Delta d)/d = (\Delta\lambda)/\lambda$.

To add to this approach, we used Cauchy dispersion formula to represent the refractive index and the extinction coefficient of MgO: $n(\lambda) = A_n + B_n/\lambda^2 + C_n/\lambda^4$ and $k(\lambda) = A_k + B_k/\lambda^2 + C_k/\lambda^4$. Therefore, the transmission spectra of the MgO/glass-substrate can be calculated as a function of thickness d and 6 parameters of Cauchy dispersion formula: $T(d, A_n, B_n, C_n, A_k, B_k, C_k)$. The actual determination of the above 7 parameters was carried out by a non-linear regression. In particular, we used the Levenberg-Marquardt algorithm to minimize the difference between the measured and the dispersion-function-based calculated transmission spectra. We assumed uniform thickness in calculating the transmission spectra for non-linear regression analysis; the small thickness variation within the measurement area was neglected.

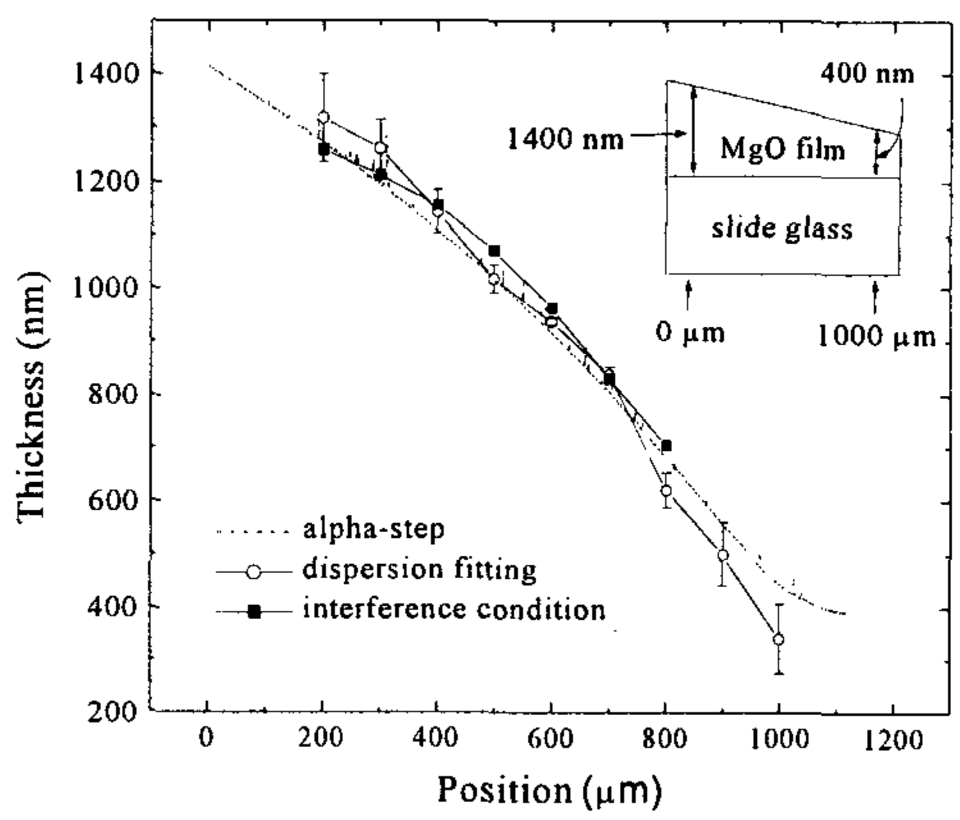

Fig. 3 A comparison of optically determined thickness variation with α-step measurement result.

In Fig. 3, we compared the position-dependent variation of the thickness, which was determined from the dispersion-based fitting, with the result of α-step measurement. The agreement between the optically determined thickness and the α-step result is excellent. Moreover, the relative thickness variation, which was determined from the shift of the transmission-maximum position, shows consistent result when converted into the absolute thickness.

After verifying the thickness mapping capability, we used the microscopic spectrophotometer to quantify the erosion of the MgO layers in the real ac-PDP cells. In Fig. 4, we compared the transmission spectra of the two ac-PDP cells measured at equivalent positions. The two ac-PDPs were operated for 9 and 1000 hours respectively, and their surface profiles measured using the α-step were presented in Fig. 2. Note that both transmission spectra were measured at the lateral distance of ~190 nm (lateral position was marked in Fig. 1) which corresponds to the middle of ITO electrodes.

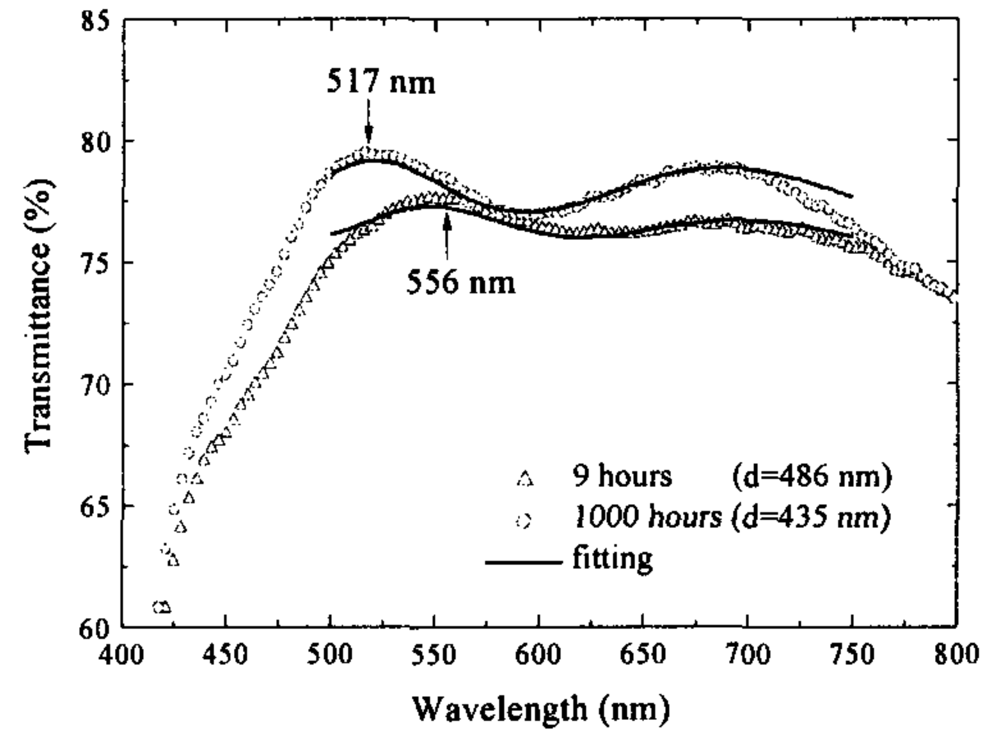

Fig. 4 Comparison of the transmission spectra of ac-PDP cells operated for 9 and 1000 hours.

The shift of the transmission-maximum to the shorter wavelength can be attributed to the operation-time-dependent progress of erosion. More specifically, we estimate that the observed shift corresponds to the additional erosion of ~7%: $(\Delta d)/d = 0.07$. In estimating the relative thickness variation, we assumed that only MgO layers are in a coherent limit and consequently responsible for the observed interference. This assumption is reasonable since the dielectric layer is very thick (~30 μm). We also neglected the ITO electrode underneath the dielectric layer due to the very small difference between their refractive indexes.

We also used the fitting method based on dispersion function to determine the actual thickness of MgO layers corresponding to the transmission spectra presented in Fig. 4. Aforementioned Cauchy-dispersion formula was used to represent the optical constants of MgO, and transmission spectra was calculated for the structure of MgO/dielectric/ITO/glass-substrate as a function of MgO thickness d and 6 Cauchy-dispersion parameters. As presented in Fig. 4, excellent fit was obtained for the thickness of 486 and 435 nm, which shows that the 1000-hour operated cell suffered 10% more erosion than the 9-hour operated cell.

Summary

We demonstrated that microscopic spectrophotometer is a useful tool for the quantitative study of the erosion of the MgO layer in a real ac-PDP cell. Currently, taking advantage of the non-invasive and non-destructive nature of the microscopic transmission measurements, in-situ measurement of the operation-time dependent erosion of ac-PDP cell is under progress.