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Electrical and Dielectric Properties of MgO Thin Films Prepared through Electron-Beam Deposition

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ABSTRACT

MgO thin films were prepared through electron-beam deposition onto ITO-coated glass substrates in order to measure electrical, dielectric, and microstructural properties. Design of experiments was performed in this study with the aim to understanding of the effects of processing variables, e.g., substrate temperature and filament current of an e-beam evaporator statistically. Leakage currents, relative dielectric constants, and diffraction intensities of MgO thin films were analyzed statistically, following the analysis procedure provided in the design of experiments. The leakage current level of MgO thin films has been found to be statistically significant at the level of α=0.1.

Key Words : Design of experiments, MgO, leakage current, electrical, dielectric, X-ray diffraction

1. INTRODUCTION

AC plasma display panels (PDP) are one of the most widespread flat panel displays (FPD) in commercial TV markets. Nowadays, PDPs have been replacing cathode lay tubes (CRTs), since they provides unlimited expandability in panel sizes, wider viewing angle, and brighter than the counterpart, CRTs. Furthermore, the AC PDPs are not distorted by the magnetic field unlike CRTs.

PDP consists of numerous ceramic components in module structure, such as glass substrates, transparent electrodes, dielectric layers, dielectric protective layers, barrier ribs, phosphors, addressing electrodes and so on. Since the PDPs operate under high voltage, the whole layers should withstand the highly-stressed conditions due to the high electric field. Among these layers, MgO thin films are usually employed as dielectric protective layers, because it reduces discharge voltage of AC-PDPs [1].

Most of previous works have focused on the discharge characteristics of MgO thin films [2]. This work investigates the electrical, dielectric, and microstructural properties of MgO thin films, prepared through electron-beam deposition. Furthermore, a statistical approach was applied in order to understand systematically the effects of process variables on the physical properties of MgO, through the conventional 2^2 full factorial design.

2. EXPERIMENTAL

ITO (Indium-Tin-Oxide)-deposited glasses whose size is 1.5cm*1.5cm were used as substrates for MgO thin films. The thickness of the ITO thin films was estimated to be approximately 1400Å by SEM (Scanning Electron Microscopy). In order to eliminate organic impurities on the transparent conducting oxides, ITO, the ITO-coated substrates were cleaned thoroughly with acetone in water bath sonicators for 10 min. And cleaning with methanol was performed in water bath sonicators for another 10 min. in order to remove inorganic impurities on the surface of the glass substrate. The substrates were rinsed with distillated water, followed by blowing through nitrogen gas.

MgO thin film was deposited onto the substrates by

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the e-beam evaporation method, using sintered magnesium oxide pellets (Ceramics and Chemicals Inc, Ulsan). The vacuum level of 1E^{-6} Torr, was obtained using a rotary pump and a cryo-pump. In the e-bam deposition of MgO thin films, the input variables were determined to be substrate temperature and filament current applied to the e-beam evaporator. The detailed experimental conditions are shown in table 1. The total five runs were performed following a 2^2 full factorial design with one center point. The experimental conditions are shown along with the coded units (+1, and -1, for high and low values respectively), in table 1. The time-dependent effects were eliminated by randomizing the run orders, as shown in Table 1.

After e-beam evaporation of MgO thin films, Pt electrodes were deposited by DC sputter. Pt electrodes were patterned into disks using a shadow mask. The geometry of Pt electrodes was estimated by CCD cameras. DC current-voltage characteristics were performed using a high resistivity electrometer (KE6517A, Cleveland, OH) and a low-frequency response analyzer (HP4192A, Palo Alto, CA) was employed to determine the dielectric constant. The microstructural information was obtained using Field Emission Scanning Electron Microscopy (JEOL JSM-6700F). X-Ray Diffractometer (PANanytical X'Pert Pro) was used to identify the degree of crystallization and the preferred orientation.

Table 1. Experimental conditions for design of experiments and the measured electrical properties, leakage currents, and effective dielectric constants.

A	B	log(L.C.)	Eff. Dielc
100(-1)	30(-1)	-7.7778	8.69698
100(-1)	50(+1)	-6.9983	9.09184
200(0)	40(0)	-8.1437	7.82246
300(+1)	30(-1)	-7.6983	9.66078
300(+1)	50(+1)	-6.8698	8.49844

A: substrate temperature [°C], B: filament current of the e-beam evaporator [mA], Log(L.C.) logarithmical value of leakage current in MgO thin films [A/cm^2] Eff. Dielec.: Effective dielectric constants of MgO thin films.

3. RESULTS AND DISCUSSION

In the full 2^2 factorial design, we can estimate the relative importance of primary effects and interactions and model a physical processing like MgO thin film deposition statistically. The system can be modeled as the following

$$Y = B_0 + B_1 x_1 + B_2 x_2 + B_{12} x_1 x_2 + \varepsilon \qquad (1)$$

where x_1 represents factor A, x_2 represents factor B, and x_1x_2 represents the two factor interaction, especially the AB interaction. B_0 is the grand average of the observations, and B_1, B_2, B_{12} are estimated by one-half of the corresponding effect values and ε is a random error [3]. The recent work was performed with a conventional full-factorial design; two factors with two levels and one center point, leading to five experiments. We analyzed the results of these experiments statistically for leakage currents (L.C.), effective dielectric constants (χ), ratio of the intensity of MgO (200) peak to the intensity of ITO (222) peak which is the main diffraction peak of the substrate (I (MgO200)/ I (ITO222)) and ratio of the intensity of MgO (220) peak to the intensity of ITO main diffraction peak (I(MgO220)/I(ITO222)).

Fig. 1 shows the current-voltage characteristics of the MgO thin films. The leakage currents are calculated at 1.0E^{-5} V/cm. The statistical results for leakage current are summarized in Table 2 with regard to the

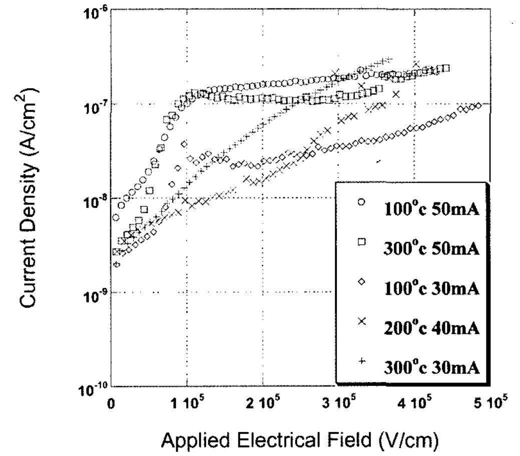

Fig. 1. Current-voltage characteristics of MgO thin films.

Table 2. Estimated effects and coefficients for leakage currents (The output value is the logarithmic value of leakage currents).

Term	Effect	Coefficient
Constant		-7.336
Temperature	0.104	0.052
Current	0.804	0.402
Temperature*Current	0.025	0.012

output parameter, i.e., estimated coefficients and effects. According to Table 2, Fig. 2 and Fig. 3 represent the normal plot and Pareto chart of the estimated effects constructed. From Table 2, the main effects, i.e., the effects of substrate temperature and filament current are positive. In other words, the leakage current increases with increasing the temperature of substrate and filament current. As shown in Fig. 4, the main effects of the filament current are larger than those of the substrate temperature. At the level of $\alpha=0.1$, the filament current is statistically significant. From the interaction plot of Fig. 5, no interaction between the temperature of substrate and the filament current is found from the parallel features of the two lines. Unlike those of leakage currents, the other properties were found to be statistically insignificant.

The capacitance-voltage characteristics of the MgO thin films are shown in Fig. 6. The capacitance was measured at 100 kHz. The relative dielectric constant (χ) is calculated by following equation.

$$\chi = (C/\varepsilon_0)(A/d) \tag{2}$$

where C represents the measured capacitance of MgO thin films (F), ε_0 permittivity of the vacuum (F/m), A represents contact area of Pt electrodes deposited on MgO thin films and d represents thickness of MgO thin films. The SEM images of the MgO thin films

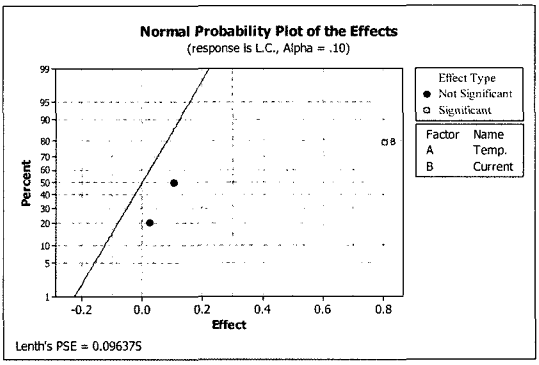

Fig. 2. Normal plot of leakage currents at the level of $\alpha=0.1$.

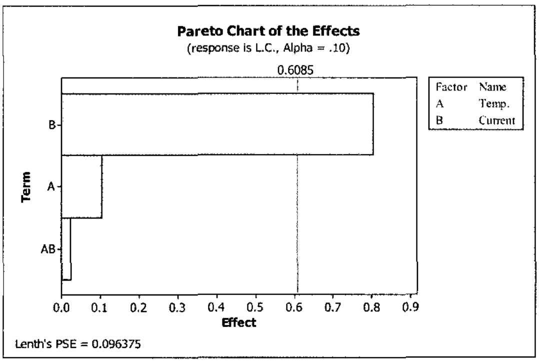

Fig. 3. Pareto chart of leakage currents from experiment.

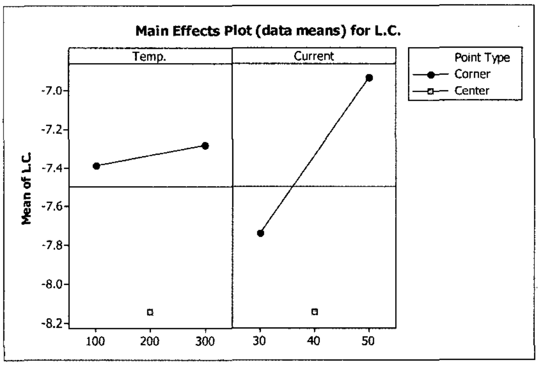

Fig. 4. Main effects plot in leakage currents in MgO thin films.

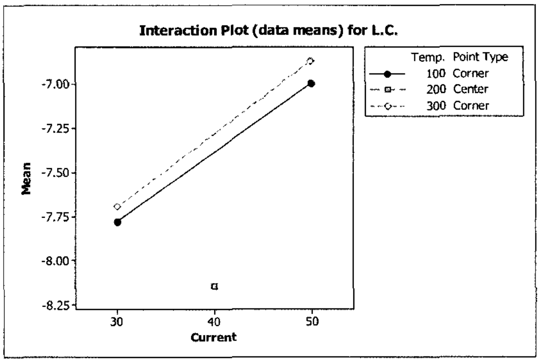

Fig. 5. Interaction plot in leakage current in MgO thin films.

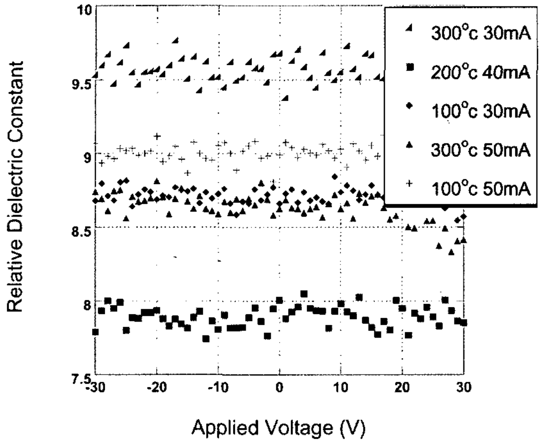

Fig. 6. C-V characteristics of MgO thin films.

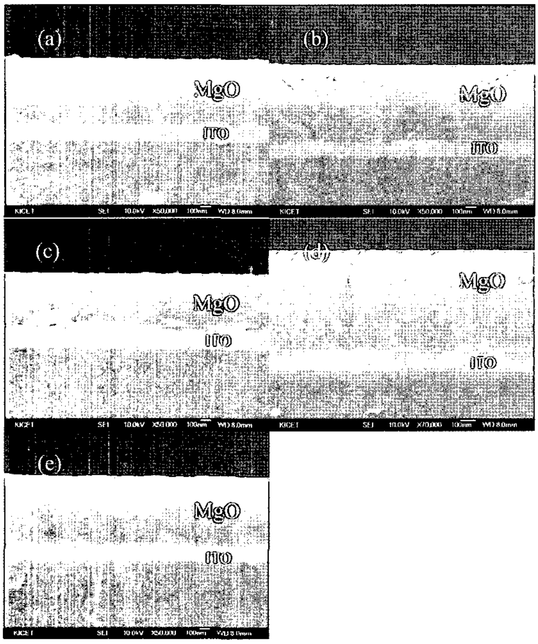

Fig. 7. The cross-section images of MgO thin films: (a) 100 and 30 mA, (b) 100 and 50 mA, (c) 200 and 40 mA, (d) 300 and 30 mA, and (e) 300 and 50 mA.

are shown in Fig. 7. The calculated dielectric constants are shown in table 1. The dielectric constant of the MgO thin film is quite similar to 9.6, the reported value of MgO[4].

The XRD data of the MgO thin film are shown in Fig. 8. In order to analyze crystallinity and preferred orientation of MgO thin films quantitatively, the intensities of MgO thin films were compared using (200) and (220) diffraction peaks. For quantitative reference, the (222) diffraction peak was chosen as a major leak of the ITO thin film deposited onto the glass substrates. From Table 3, the MgO (200) diffraction intensity increases with increasing substrate temperature and decreasing filament current. The effect of filament current appears to be more dominant, than that of substrate temperature. On the other hand, the MgO (220) intensity increases with substrate temperature and increasing filament current. From the above XRD results, the substrate temperature is determined to be a major factor in the positive manner. Among all the variables, current affects the major characteristics in MgO thin film most. As the filament current of e-beam evaporator increases, leakage current of MgO thin film increases, MgO (200) intensity decreases, and MgO (220) intensity increases. Since MgO (200) is denser and more stable than MgO (220), it is reasonable that leakage current of MgO thin film decreases with increasing MgO (200) intensity. High filament current provide significant kinetic energy for the deposited species, leading to stable orientation. High filament current was reported to produce preferred MgO (200) orientation in the previous work [5]. But in our work, preferred MgO (220) orientation is obtained as filament current increases.

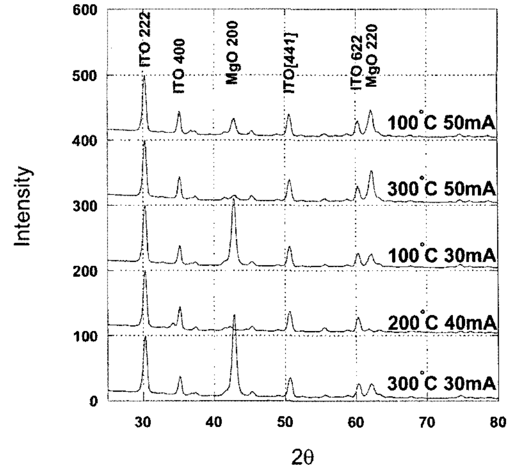

Fig. 8. XRD data of MgO thin films deposited through electron-beam deposition.

Table 3. Experimental condition for the five runs and calculated data.

A	B	I(MgO200) /I(ITO222)	I(MgO220) /I(ITO222)
100(-1)	30(-1)	1.1054	0.2564
100(-1)	50(+1)	0.4403	0.4618
200(0)	40(0)	0.1428	0.1056
300(+1)	30(-1)	1.3221	0.2646
300(+1)	50(+1)	0.4387	0.5396

A: substrate temperature [°C], B: filament current of the e-beam evaporator [mA] I(MgO200)/I(ITO222): Intensity ratio of MgO (200) to ITO (222), and I(MgO220)/ I(ITO222): Intensity of MgO (220) to ITO (222).

This work reports the preliminary information on MgO thin films deposited through electron-beam deposition. In order to optimize the MgO thin films in the PDPs, further investigation should be performed, e.g., defect chemistry in MgO, and the relation between MgO defects and luminescent characteristics.

4. CONCLUSION

MgO thin films were prepared on ITO glasses by an e-beam evaporation method. Experimental variables, substrate temperature and filament current of the e-beam evaporator, were controlled and analyzed through design of experiments. The filament current is found to be more dominant in determining the physical properties of MgO thin films, leakage current and XRD orientation. The current work suggests the experimental scheme towards specified objective, e.g., in order to maximize the (200) MgO peak as a major orientation, the low value should be applied to the filament current.

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