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Discharge characteristics of protective LaB_6 thin films in an AC plasma display panel

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Lanthanum hexaboride (LaB_6) thin films were used as protective layers in alternating current plasma display panels (AC-PDPs). The firing voltages and discharge delay time of protective LaB_6 thin films were evaluated and compared with the conventional protective MgO layers in planar-type test panels filled with 5%–15% Ne-Xe. By employing LaB_6 thin films as protective layers, both the firing voltages and discharge delay time decreased drastically. Improvements in the discharge properties of the LaB_6 thin film could be attributed to the lower work function, offering more priming electrons during the discharge process.

lanthanum hexaboride (LaB_6), protective layer, firing voltages, discharge delay time

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Owing to their high luminance, high contrast, wide viewing angle, and full color display, alternating current plasma display panels (AC-PDPs) have become regarded as one of the leading flat-panel display devices today. Among the elements composing today's AC-PDPs, the panel's protective layer plays an important role in influencing the driving voltages of AC-PDPs and preventing AC-PDPs from ion sputtering. However, the discharge voltages of AC-PDPs with conventional magnesium oxide (MgO) protective layers are still considered to be too high to permit standard integrated circuits. Hence, it is necessary to develop a new protective layer to obtain high-performance AC-PDPs.

Recent research in this field has focused on doping MgO with impurities or coating an additional thin protective layer on the MgO layer in hopes of enhancing the secondary electron emission yield of the protective layer in AC-PDPs; this research includes studies into the effects of MgO doped with ZnO [1], MgO doped with Si [2], MgO doped with SiO_2 [3], $MgAl_2O_4$/MgO double layers [4], SrO/MgO double layers [5], LaF_3/MgO double layers [6], and so on. In addition, some new protective materials such as La_2O_3, CeO_2, SrO, and SrCaO cold cathodes have also been developed [7,8] with the aim of replacing the conventional MgO protective layer to improve the overall performance of AC-PDPs.

In this letter, we propose the use of a lanthanum hexaboride (LaB_6) thin film as a new protective layer in AC-PDPs. This film's many promising qualities include its low work function (2.3–3.0 eV), low sputtering yield, and excellent mechanical stability against ion bombardment. A handful of reports on the application of LaB_6 to be as a cathode material for PDPs have been published in recent years; however, these studies only focused on LaB_6 thick films that were not transparent, and the films' gas discharge properties were not discussed in detail [9,10]. In our study, protective LaB_6 thin films with a high transmission rate were prepared by the electron beam evaporation method. Moreover, the discharge characteristics of these films were analyzed and compared with those of MgO thin films by measuring the discharge delay time (t_d) and firing voltages (V_f) in test cells filled with Xe-Ne gas mixtures.

In our study, the gas-discharge characteristics of LaB_6

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thin films and MgO thin films were measured in a planar-type test panel by the opposite discharge method. Considering the very small size of the discharge cell of AC-PDPs, a macro cell was introduced, based on the similarity law and Paschen's law in gas-discharge theory. It has previously been established that the gap length of discharge cells in general AC-PDPs is about 100 μm, and the pressure of the cells filled with inert gases (Ne and Xe) is about 300–400 torr. Thus, in accordance with the similarity law and Paschen's law, the gap length of the discharge cell in our experiment was set to ~3 mm (i.e. the magnification of 30), and the pressure was set to 1–20 torr. A schematic diagram of our macro-cell testing configuration is shown in Figure 1.

In our experiment, an ITO layer with a thickness of 130 nm was prepared by the magnetron sputtering method, and a transparent dielectric layer with a thickness of 21 μm was formed by using the screen-printing method. A 5 mm diameter MgO thin film was subsequently deposited on the dielectric layer as a protective layer and a LaB_6 thin film was then deposited on a separate dielectric layer with the same diameter. Both films were fabricated by electron beam deposition, as summarized in Table 1. In addition, an ultraviolet-visible spectrophotometer was used to test the visible light transmittance of both films. This assessment indicated that the LaB_6 thin film with a thickness of 40 nm presented high transmission of ~90% in the visible light wavelength, which was very similar to the MgO thin film with a thickness of 800 nm.

A previous study indicated that the breakdown voltages in AC-PDPs cells decreased significantly as the ion-induced secondary electron emission of the panel's protective layer increased [11]. This study also reported that the ion-induced secondary electron emission efficient of a protective MgO layer with (111) surface had the highest value in comparison with the other orientations of (200) and (220).

Figure 2(a) shows the XRD pattern of the fabricated MgO thin film tested in our experiment. It can be seen that the MgO thin film has perfect crystallinity and the intensity of (111) orientation peak is the strongest. Thus, we can conclude that our fabrication technology has achieved a protective MgO layer with high ion-induced secondary electron emission efficiency.

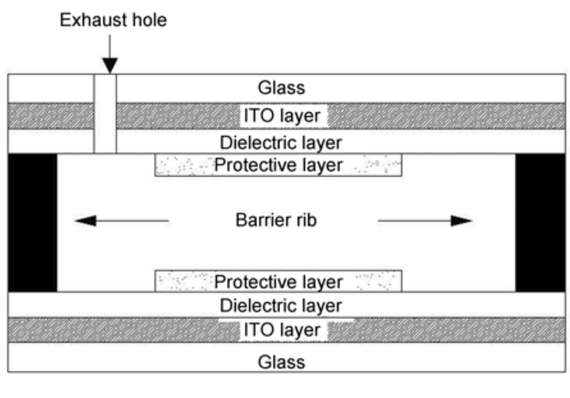

Figure 1 Schematic diagram of the macro-cell configuration used for the investigation of discharge properties of LaB_6 thin films and MgO thin films.

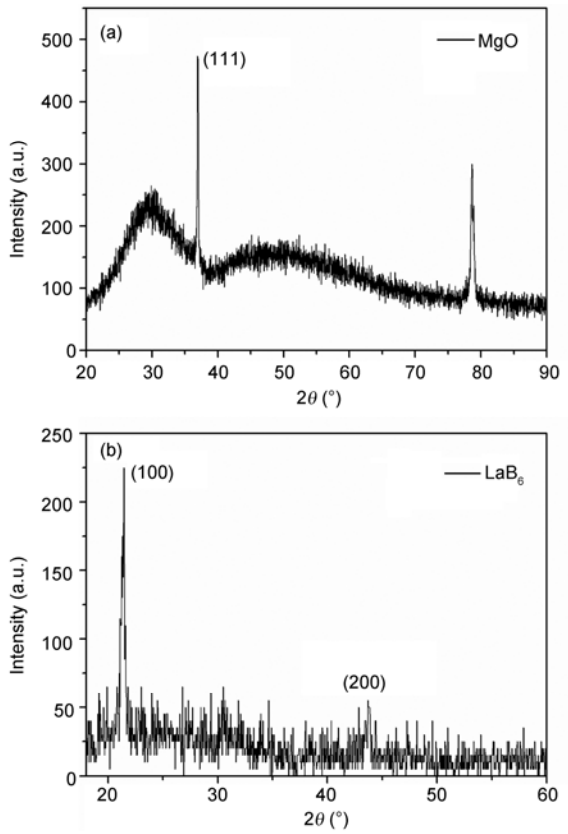

Figure 2 The XRD patterns of fabricated thin films. (a) MgO thin film; (b) LaB_6 thin film.

In addition, according to some published reports focusing on the relationship between work function and the crystal face of LaB_6, the work function of various orientations is in the range of 2.41–2.90 eV, and the order is described as: (346) < (100) < (110) < (111) [12,13]. Figure 2(b) shows the XRD pattern of our fabricated LaB_6 thin film with background noise excluded. With a strong preferred orientation to the (100) plane, this film exhibits fine crystallinity. We have thus concluded that the evaporating conditions shown in Table 1 are feasible for obtaining low work-function LaB_6 thin films that are very suitable for AC-PDPs.

As shown in Figure 3, the firing voltages and discharge

Table 1 Deposition conditions of MgO thin films and LaB_6 thin films

	MgO thin films	LaB_6 thin films
Vacuum	3×10^{-8} torr	9×10^{-7} torr
Distance between Substrate and target	50 cm	50 cm
Substrate temperature	100°C	400°C
Diameter of thin films	5 mm	5 mm
Thickness of thin films	800 nm	40 nm

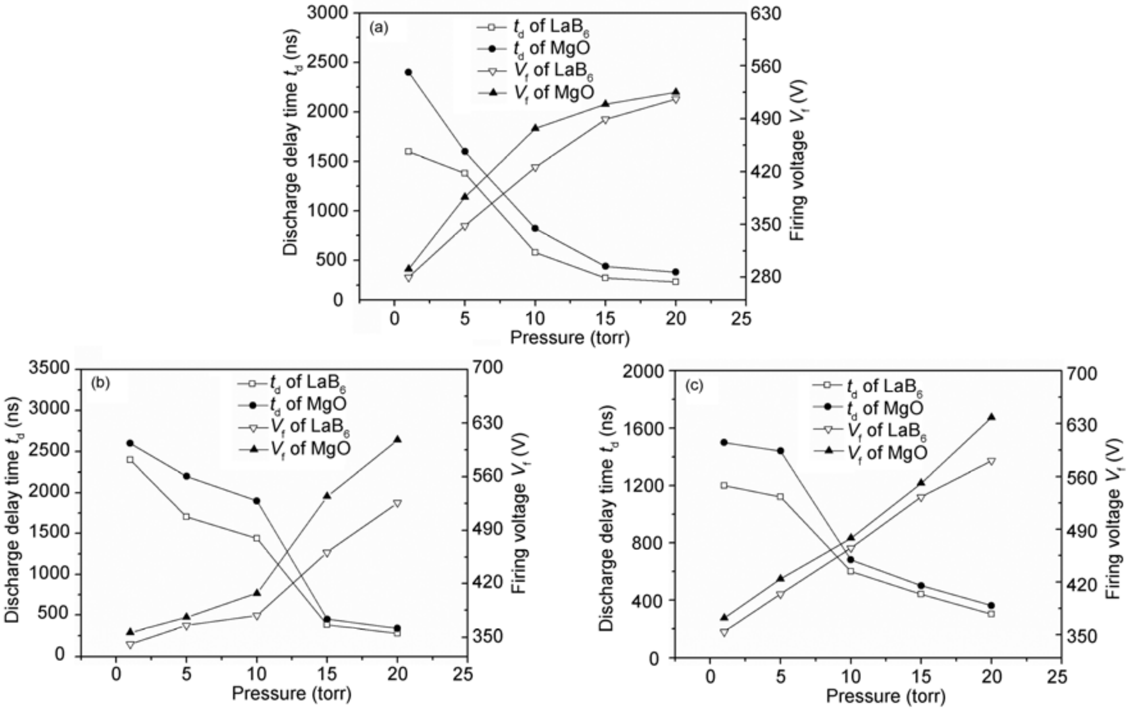

Figure 3 Firing voltages and discharge delay time versus gas pressure of the test panels with MgO and LaB_6 protecting layers. (a) Xe 5%; (b) Xe 10%; (c) Xe 15%.

delay time of fabricated LaB_6 thin films and MgO thin films were measured in 5%–15% Ne-Xe and plotted against gas pressure. We observed two important phenomena in the firing voltage results:

(1) As the pressure increased, the firing voltages of both the LaB_6 thin films and MgO thin films increased, indicating that the device worked in the right-hand side of the Paschen curve. A possible reason for this finding is that the minimum *pd* (where *p* and *d* are pressure and gap length, respectively) adopted in our experiment is about 3 torr mm, which is still higher than the lowest point (i.e. turning point) in the complete Paschen curve.

(2) No matter how large the pressure was, LaB_6 thin films presented much lower firing voltages than MgO thin films. The lower firing voltages of LaB_6 thin films are likely due to their lower work function, offering an important and effective supplement for the priming source needed in the gas discharge.

It is known that the discharge time lag is composed of the formative time lag (t_f) and the statistical time lag (t_s) [14, 15]. The formative time lag is defined by the time required to build up the discharge through the avalanche process from the end of the initiatory lag, which mainly relies on the electric field strength, as shown in eq. (1). On the other hand, the statistical time lag is defined by the time elapsed between the instant application of external voltage and the arrival of initial seed electrons in the gap, which represents the variation of the priming state of the cell, as shown in eq. (2).

$$t_f = t_+ + t_e = \frac{d}{EK_+} + \frac{d}{EK_e} \approx \frac{d}{EK_+} \propto \frac{1}{E}, \tag{1}$$

$$t_s = \frac{1}{n_0 P_S} \propto \frac{1}{n_0}, \tag{2}$$

where t_+, t_e, E, K_+, K_e, n_0, and P_s are the time taken for the ion to arrive to the cathode, the time taken for the electron to arrive to the anode, electric field strength, mobility of ion, mobility of electron, number of seed electrons, and the chances that an electron will produce an avalanche, respectively. As the gas pressure increases, a higher E is required to form the avalanche process and t_f is reduced according to eq. (1). As a result, the discharge delay time for both LaB_6 thin films and MgO thin films decreased. Moreover, owing to the lower work function of the LaB_6 thin film, there are more priming particles in the cell and the t_s of LaB_6 thin film is shorter. Hence, the discharge delay time of the LaB_6 thin film is much shorter than that of MgO thin film, as shown in Figure 3.

In conclusion, the test cells with LaB_6 thin films at Xe-Ne gas mixtures consistently showed lower firing voltages and shorter discharge delay time, compared with the conventional cells protected by MgO thin films. The possible mechanism is due to the lower work function of LaB_6 thin films, which offer more of the priming electrons necessary to the discharge process of AC-PDPs.

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1 Jung E Y, Lee S G, Sohn S H, et al. Appl Phys Lett, 2005, 86: 153503–153505
2 Ha C H, Kim J K, Whang K W. IEEE Trans Electron Devices, 2008, 55: 992–996
3 Lee H K, Kim J W, Park S J, et al. Thin Solid Films, 2007, 515: 5113–5117
4 Jeoung J M, Ko B D, Lee H J, et al. Jpn J Appl Phys, 2006, 45: 7901–7904
5 Jung H Y, Lee T H, Kwon O, et al. IEEE Electron Device Lett, 2010, 31: 686–688
6 Lee W T, Im S J, Han J G, et al. Jpn J Appl Phys, 2003, 42: 4501–4503
7 Urade T, Lemori T, Osawa M, et al. IEEE Trans Electron Devices, 1976, ED-23: 313–318
8 Uchida G, Uchida S, Kajiyama H, et al. J Appl Phys, 2009, 106, 093301
9 Ono M, Hara S, Shiga T, et al. LaB6: New cathode material for ac PDP TVs. In: International Display workshops Niigata, Japan, 2008: 765–768
10 Munemoto E, Yoshida K, Awaji N, et al. In: International Display Research Conference, San Diego, CA, USA, 1988: 114–117
11 Lim J Y, Oh J S, Ko B D, et al. J Appl Phys, 2003, 94: 764–769
12 Gesley M, Swanson L W. Surf Sci, 1984, 146: 583–599
13 Oshima C, Bannai E, Tanaka T, et al. J Appl Phys, 1977, 48: 3925–3927
14 Loeb L B. Rev Mod Phys, 1948, 20: 151–160
15 Kim J S, Yang J H, Kim T J, et al. IEEE Trans Plasma Sci, 2003, 31: 1083–1090