



Thin AC-PDP Vacuum In-line Sealing Using Direct-Joint Packaging Method

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In this work, we have improved vacuum in-line sealing technologies for plasma display panels (PDPs) using the direct-joint packaging method, which is different from the conventional packaging method in the aspects of exhaust hole and tube. We use the glass frit and B-stage organic binder materials for packaging. The sintering process is performed for both materials before packaging to reduce out-gassing and to optimize conditions. To get the high vacuum conductance, we suggest the lump structure on seal-line. The vacuum conductance using lump structures provides better pumping efficiency than tube packaging by theoretical calculation. The packaging temperatures for glass frit and organic binder are 380 and 175°C, respectively. The 4 in. alternating current (ac)-PDP is successfully packaged in He-Ne(27%)-Xe(3%) ambient and fully emitted with brightness of about 1000 cd/m². The long-term reliability of packaged PDP is evaluated through both the light emission characteristics and a driving test for one year. This method has the advantages of a simple, brief, low cost process, improved gas uniformity by high vacuum efficiency, and thin panel fabrication achieved by the removal of the exhaust hole and tube.

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The plasma display panel (PDP) is one of the most promising flat panel displays (FPDs). The advantages of PDP devices are well-known, simple structure, high resolution, fast response time, large screen size, and wide angle view.^{1,2} A PDP panel is normally operated at gases ambient to generate the VUV (vacuum ultraviolet) ray from xenon in the penning mixture gas.³ A packaging technology is very important to provide protection of the devices from surrounding effects related to lifetime and durability. In general, PDP has been packaged by the cathode ray tube (CRT)-like method that is proven to be limited in terms of the out-gassing, metal oxidation by high-temperature process, difficult handling, and the lower vacuum conductance owing to small inner volume.^{4,5} Also, PDP sealing is carried out by cart-type packaging equipment, which has problems such as difficult tube alignment between panel and system, easy tube cracking, unstable gas uniformity, and the requirement of a second tip-off process owing to long tube length. Also, residual gases such as CO and CO₂ cause the increase of the firing or sustained voltage. So, the tubeless sealing method using electrostatic bonding was introduced last year. It solves the previously mentioned problems. But it needs a support glass with an amorphous silicon film deposited in order to be packaged.⁶ Also, the vacuum in-line process was reported a long time ago, and some groups tried the vacuum in-line packaging using a glass frit. But, this technology was not developed clearly owing to problems of out-gassing of the glass frit.

This paper reports a PDP vacuum in-line packaging technology using the direct-joint packaging method, which is different from the conventional packaging method in the aspect of exhausting the hole and tube. In order to investigate the surface contamination by glass frit Auger electron spectroscopy (AES) analysis for sintering conditions is carried out. The long-term reliability of packaged PDP is evaluated through both the light emission characteristics and driving test. We packaged a 4 in. ac PDP with total thickness of 6 mm by the previously mentioned process. Also, we tried a low-temperature sealing process by organic binder under 200°C. The advantages of this method are a simple, short time, low cost process, improved gas uniformity by high vacuum efficiency, and thin panel fabrication by removal of the exhaust tube.

Experimental

A surface discharge ac PDP with a three-electrodes system is widely used, in which X and Y electrodes covered with dielectric layer are parallel to each other in the front glass. An MgO protective

layer is deposited on the dielectric layer by electron beam evaporation with 0.5 μm thickness. The address electrode and barrier rib are perpendicular to the two sustaining electrodes in the rear glass. Figure 1 shows the schematic diagram of the proposed structure by the direct-joint packaging method. In this method, we use only adhesive materials, such as glass frit and organic binder, without exhausting the hole and tube. The seal line is drawn on the rear glass by the dispenser or screen printer. Lumps are formed, which provide a pumping-out path before assembly between front and rear glass plates. The pumping-out path dimensions between lumps are related to a pumping efficiency from the inner to the outer panels. In the case of the glass frit, it is sintered in N₂ ambient at a temperature of 380°C, and the front plate is put on the rear plates. To use the direct-joint packaging method, the sintering process of the glass frit is very important. If we do not perform a pretreatment process, the surface will be contaminated by Pb, C, and O, which are investigated by Auger electron spectroscopy. However, the panel is put in the vacuum chamber followed by pumping-out to 1×10^{-6} Torr at a temperature of 250°C. The Xe(3%)-He(27%)-He gases are filled afterward. The panel is heated to 350°C by halogen lamps. The melting temperature of the glass frit in the vacuum environment by halogen lamps is lower than one in atmosphere heated by a furnace. The process time is less than 4 h. In the case of an organic binder packaging, the process is simpler than other processes because a low-temperature process is possible. We use the B-stage type binder, which has a stronger bonding strength and low reaction rate with moisture than conventional adhesive materials. First, we form the seal-line of the binder with a screen printer followed by performing a soft baking at 95°C. Then the panel is put in the vacuum chamber followed by pumping-out to 1×10^{-6} Torr at a temperature of

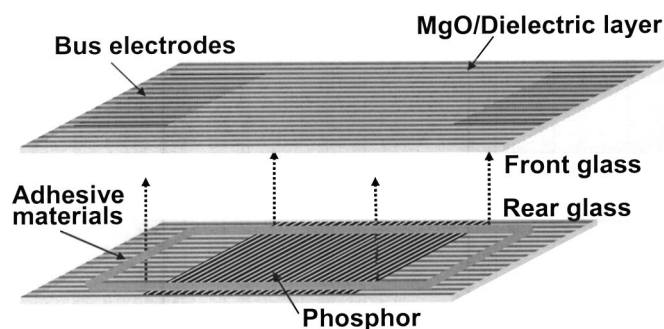


Figure 1. Schematic diagram of direct-joint packaging method.

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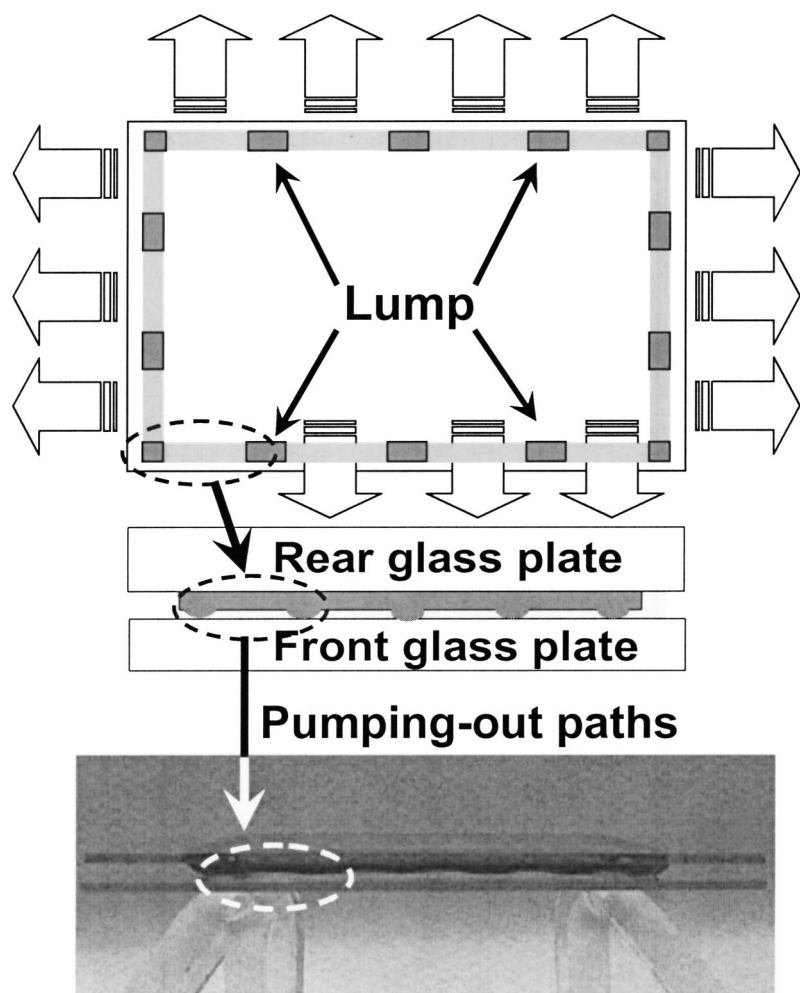


Figure 2. Schematic diagram of lumps and pumping-out paths.

100°C. A gas mixture is put in and the panel is packaged at 175°C. The process time is less than 3 h. The pressure is about 350 Torr at room temperature when the panel is packaged. The 4 in. PDP is successfully packaged and fully emitted for each method.

Vacuum Efficiency

Figure 2 shows a schematic diagram of lumps and pumping-out paths. Also, it shows the cross-sectional diagram and photograph of lumps formed on the seal line. The distance between lumps provides a pumping-out path from the inner to the outer panel. We can show the pumping-out path in the image. Then the path is shown in the side of view panel. The rear glass plate is aligned on the front glass. The pumping-out path dimension between lumps is related to pumping efficiency. To know the vacuum efficiency, the theoretical value is calculated using structural conductance, which is the ability of the

pipe to allow a unit volume of gas to pass through per time.^{5,7} Then, conductance, *C*, of rectangular shape for one path becomes

$$C = 31.1 \frac{L^2 H^2}{(L + H)W} \text{ [L/s]} \quad [1]$$

where, *L* is the distance of lumps, *H* is the lump height, and *W* represents the seal-line width.

Table I. Theoretical conductance values in direct-joint packaging.

Path	Lump	Conductance for seal line (L/s)		
		1 cm	20 cm	40 cm
1	9	0.0018	0.036	0.072
3	7	0.0059	0.118	0.236
5	5	0.01	0.2	0.4
7	3	0.014	0.27	0.56
9	1	0.0182	0.364	0.728

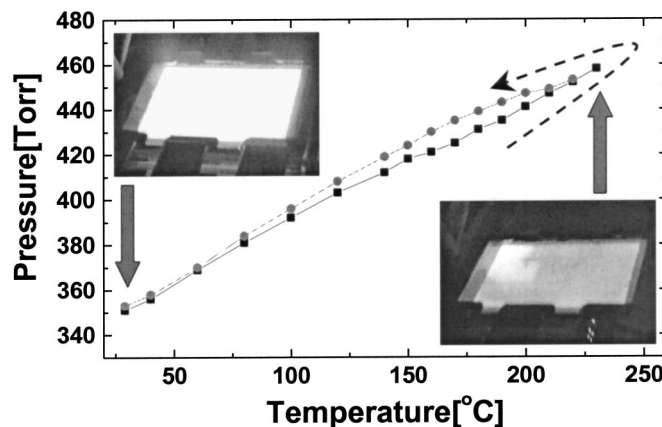


Figure 3. Reversible properties of PDP mixture gas and emission color for temperature variation.

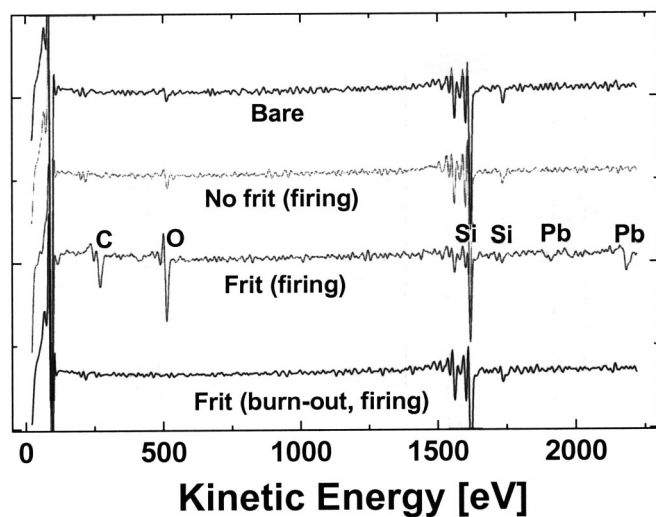


Figure 4. Contamination analysis on silicon wafer surface by AES.

The conductance values as a function of path size and seal line lengths are calculated and summarized in Table I. In this paper, we form a pumping-out path of 7 mm distance and a lump of 3 mm length per unit length of 1 cm with 150 μm height and 3 mm width on the seal line. The calculated conductance is 0.0139 L/s per cm, which is similar to a conductance of the exhausting tube having 2 mm diam and 4 cm length. Therefore, we can get the linear increased conductance through the increase of the PDP size, because of the many paths of the seal-line length. Based on the theoretical calculation, we get a total conductance of 0.41 L/s in our panel with a seal-line length of 29 cm. Since the conductance linearly increases by increasing the panel size, it is possible to overcome the limitations of the pumping-out problem which is the drawback of the conventional method.

Results and Discussion

The packaging temperature is one of the important factors for hermetic sealing and driving. Therefore, we investigated dependent and reversible properties as a function of temperature, pressure, and light emission, as shown in Fig. 3. The pressure of the gas mixture is

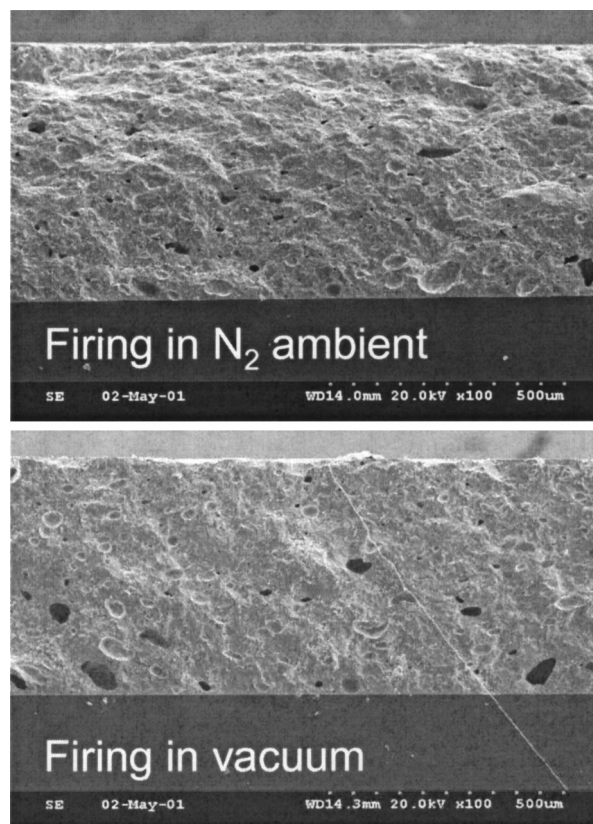


Figure 5. Cross-sectional view of glass frit sintered in a vacuum environment.

increased during heat-up and returned to its initial pressure during cool-down. Also, we show the changes of the lighting color for temperature variation. The green color at room temperature is changed to a dark pink color at around 250°C, but it recovers its ordinary state at room temperature. Therefore, we think that the packaging in high-temperature enables the application of these methods.

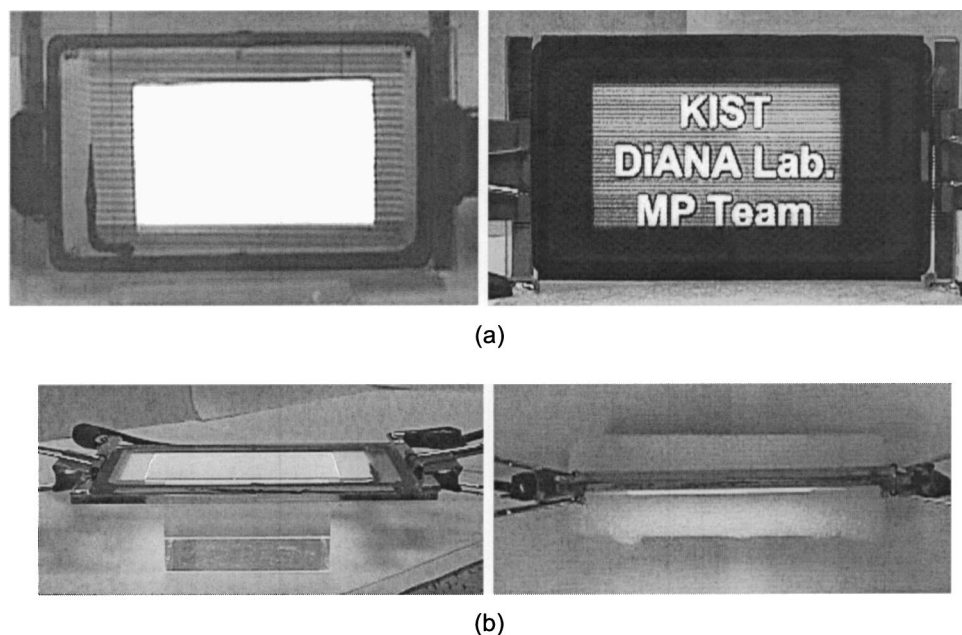
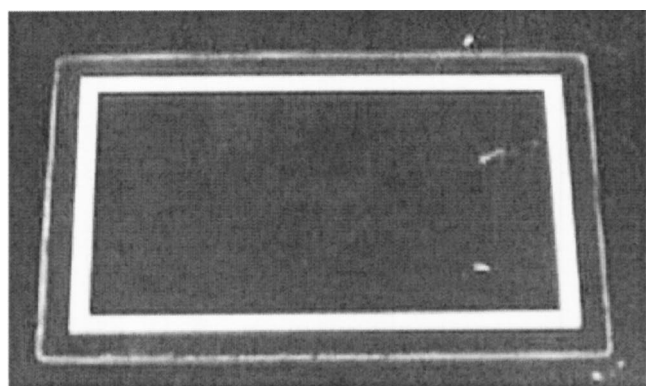
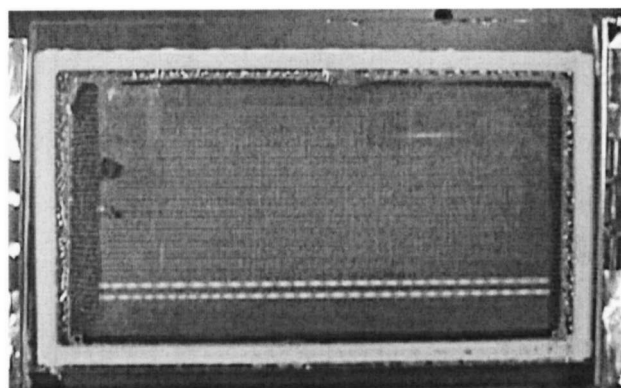


Figure 6. Green light emission from the packaged 4 in. ac-PDP, (a) front view and (b) side view.



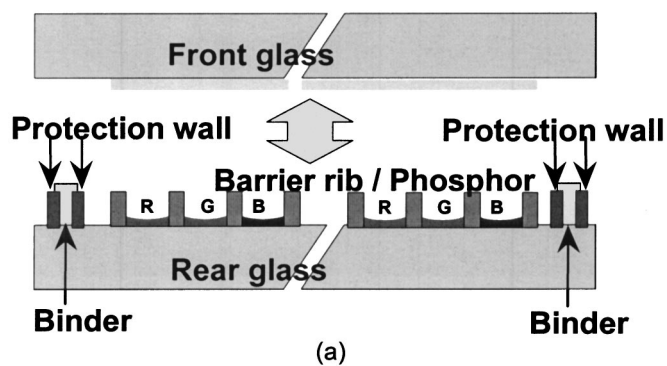
(a)



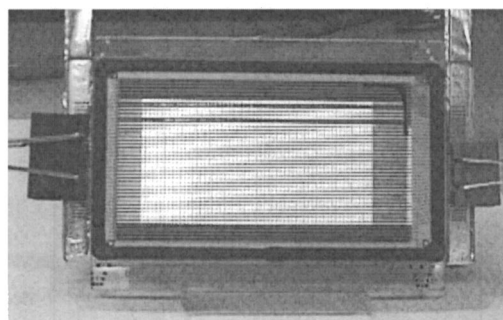
(b)

Figure 7. Photograph from the organic binder sealing method, (a) seal-line by screen printing and (b) line emission of sealed panel.

Glass frit material.—To package by the direct-joint packaging method, the sintering process of the glass frit is very important. The glass frit is mainly composed of PbO , SiO_2 , and a chemical vehicle. If we do not perform a burn-out process or critical temperature process, the device surface is contaminated by Pb, C, and O. In order to investigate the above problem, we carried out the Auger electron spectroscopy (AES) analysis. We prepared two panels. The burn-out process of the glass frit at 380°C was performed on one panel. The burn-out process at low temperature was performed on the other panel. We placed the clean Si wafer in the panel and fired it in the vacuum environment. Figure 4 shows the AES analysis results for the Si wafer surface. Annealing on the no frit sample is carried out in the same conditions as in the case of the bare sample. From these results, we can show the C, O, and Pb peaks. But, other peak were not observed under our process conditions. Also, the bubble in a glass frit is caused by out-gassing and microleaks by gas permeation. Therefore, the optimized process is required to remove a bubble. We have solved the above problem by the firing process control. Figure 5 shows the cross-sectional view for the sintered glass frit in vacuum, which is in the same state as in the condition of the atmosphere. In general, the origin of bubbles is ionized oxygen from PbO generated during the high-temperature process. Therefore, temperature control is very important in atmosphere or vacuum ambient. Figure 6 shows the full green light emission image for front and side views from successfully packaged 4 in. ac-PDP with 6 mm thickness by the above process. This panel has no barrier rib and address electrode. Then, the luminance is about $950\text{--}1000\text{ cd/m}^2$ at an arbitrary spot on the panel. The maximum firing voltage of 220 V with 50 kHz of driving frequency is applied to the panel without address voltage. The voltages linearly decrease with the operating



(a)



(b)

Figure 8. Direct-joint packaging with protection wall, (a) schematic diagram and (b) photograph of the light emission image.

time variation for 160 h and are saturated afterward. From the observed results, we propose that the direct-joint packaging method can be applied to PDP packaging, and provide a low cost, short time process, high vacuum efficiency, and simple packaging process.

Organic binder material.—In the case of organic binder packaging, the process is simpler than other processes because the low-temperature process is possible. We apply this method to PDP packaging using a B-stage binder. First, we formed the seal-line of the binder with the screen printer followed by performing a soft bake at 95°C , as shown in Fig. 7a. The packaging is performed at 175°C in a vacuum chamber of mixed gas environment. We use the B-stage epoxy, which has a stronger bonding strength and low reaction rate with moisture than conventional adhesive materials. The 4 in. ac-PDP is sealed and emitted as a line emission, as shown in Fig. 7b. But the firing voltage is linearly increased as time goes by and the PDP did not operate later. We think that this occurred because of contamination or leakage of the gas mixture. The contamination

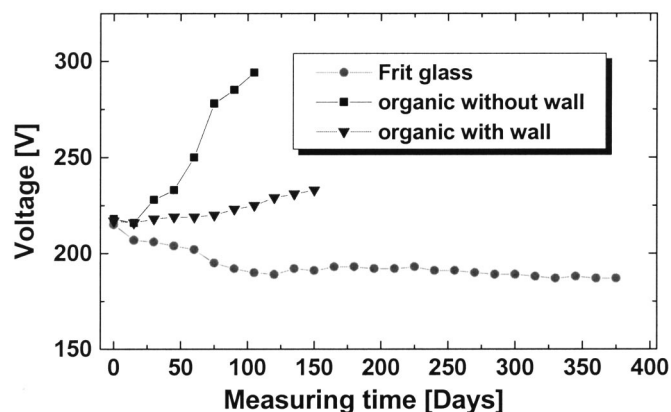


Figure 9. Driving voltage variation properties for measuring time.

problems can originate from two possibilities, such as gas permeation through the bonded interface and out-gas from the organic binder in seal region. In order to investigate the possibility of gas permeation, we measure the leak rate with a helium microdetector. The packaged panel is put in the vacuum chamber followed by filling the chamber with helium gas to 1400 Torr. Several hours later, we measure the helium leak rate in the other chamber. The obtained results are $1.2\text{--}2.7 \times 10^{-7} \text{ cm}^3/\text{s}$, which is suitable for a PDP packaging application. Therefore, we think that the increasing of the driving voltage results from out-gas generated from the binder during ac-PDP operation. The temperature inside the panel is reported to be about 120°C during driving. In this try, we print a binder to the whole seal-line on the rear glass and the contact front glass. So, the binder should be exposed to the plasma during driving and will generate out-gases. This can be solved using getter material or a protection wall. Figure 8a shows the schematic diagram of vacuum in-line packaging using a protection wall, which obstructs direct contact between the binder and the plasma. The wall can be formed during the barrier rib formation process by a printing or sanding method. In this work, we fabricate the frit glass protection wall by dispensing through a second drawing. Also we filled in between the frit seal-lines with the organic binder. Figure 8b shows a photograph of an emission image of the sealed ac-PDP using the above process.

In order to investigate the driving characteristics, an external bias signal is applied to the panel. Figure 9 shows the long-term test results for three cases, such as the frit glass, and an organic seal-line with and without the protection wall. In the case of the frit glass sealing, the firing voltage is maintained with around 190 V for about 1 year. But, the firing voltage of the organic binder sealing without a protective wall is increased exponentially to 300 V in 100 days. The reason for this is thought to be due to out-gases from the organic binder, as discussed above. To solve this degradation problem, we have fabricated the protection wall as shown in Fig. 8a. Obviously, we can see that the firing voltage increasing effect is much improved by the protection wall. But, the driving voltage is increased a little at a time. We think that this problem results from a contaminated interface during the sealing process. This can be solved by using gettering or redesigning the protection wall. Further

research and expansion of this method to full emission is being investigated. The other problem is the consumption of an amount of the gas mixture because of filling the packaging chamber. This can be solved by a gas recycling system or optimized sealing chamber.

Conclusions

We propose a direct-joint packaging method, which facilitates a short packaging time of within 3-4 h without exhausting the hole and tube using an organic binder and glass frit. In the case of the glass frit the problems of out-gassing and bubble formation are solved through sintering condition control. In the case of the organic binder, driving voltage degradation is decreased by the protection wall structure. The ac-PDP is successfully packaged and fully emitted at a brightness of 1000 cd/m^2 by the direct-joint packaging method. Also the long-term reliability of packaged PDP is evaluated for one year. Therefore, we think that this method can be applied to PDP packaging to obtain the advantages such as a simple, brief, low cost process, with improved gases uniformity by high vacuum efficiency, and thin panel fabrication because of the removal of the exhaust hole and tube.

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