A PDP Vacuum In-Line Sealing Technology by using a Bubble-reduced Frit

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ABSTRACT

Improper base vacuum level in any vacuum microelectronic device, such as a Plasma Display Panel(PDP), will damage the overall performance of the device due to impurities such as H_2, O_2, CO, CO_2, and N_2. In conventional tubulation packaging technology, the obtainable base vacuum level before plasma gas filling will be very poor because of the pumping conductance limitation for such a large panel size with a small gap of 150 μm, especially due to the barrier ribs inside the PDP panel. The time required to reach any reasonable level will be too long. In this study, we performed the sealing of the two glass plates composing the PDP panel, a plasma gas filling into the panel and a hole-off (named instead of a conventional 'tip-off') process, all in a vacuum chamber, called as 'vacuum in-line sealing'. Several factors related with the heating process of a frit glass were investigated. A prepared frit glass was successfully applied for the vacuum in-line sealing approach without suffering bubbles. We successfully have fabricated an operable PDP panel with a 2-inch diagonal size by using the fully vacuum in-line sealing technology for the first time in the world. The sealing temperature of the two plates was around 330°C which corresponded to a temperature about 120°C lower than that used in a conventional air environment. The base vacuum level inside the panel before gas filling was about 5×10^{-6} Torr at the time of sealing. The total elapsed time for the sealing processes was less than 6 hours, including the gas fill and the hole-off processes.

I. INTRODUCTION

One of the most important technologies for fabricating microelectronic display devices, such as a Plasma Display Panel(PDP), Field Emission Display(FED), and Vacuum Fluorescent Display(VFD), is the one for obtaining a high vacuum level inside the panel[1-3]. In addition, sustaining the initial high vacuum level is also very important[4]. A PDP display consists of a front glass plate and a rear glass plate. The conventional fabrication process for a PDP composed of two glass plates is as shown in Fig. 1.

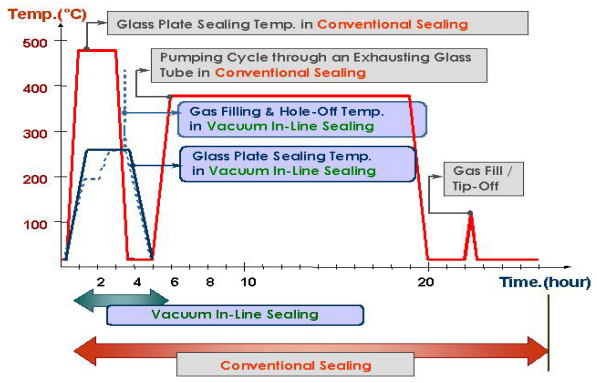


Fig. 1. Typical panel fabrication process for a PDP.

Typically, the front glass plate contains components such as ITO electrodes, bus electrodes, an insulation layer, and a MgO layer. The rear glass plate contains components such as address electrodes, reflecting layer, barrier ribs, and phosphor layers. After the fabrication of the front glass plate and the rear glass plate, the two plates are sealed together by using frit sealing followed by baking under pumping. During the baking under pumping, the panel is connected to a vacuum system through a tubulation usually around 10 cm in length and with a diameter of around 2 mm. After pumping under baking for a long time, a plasma mixture gas is introduced into the panel and tip-off is done. The base vacuum level obtainable in the conventional sealing method is limited by the pumping conductance. That is, obtaining a very a high vacuum level in the conventional sealing procedure of PDP is impossible because of the small space given by the gap of 150 μm between the two glass plates and the width of about about 320 μm between adjacent barrier ribs.

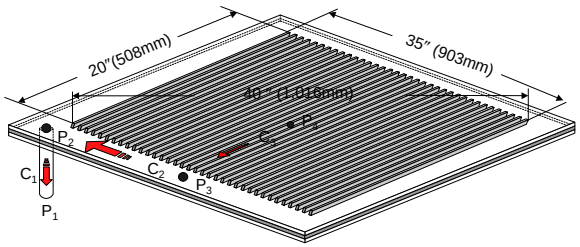


Fig. 2. PDP panel configuration showing conducting paths in a conventional sealing method.

Figure 2 shows some conducting paths in the pumping process of a 40- inch diagonal PDP panel. P_1, P_2, and P_3 correspond to the pressure values at each point and C_1, C_2, and C_3 correspond to the pumping conductance values along each path. According to the throughput equations, $Q = S_1P_1 = C_1(P_2-P_1)$, $S_2P_2 = C_2(P_3-P_2)$, and $S_3P_3 = C_3(P_4-P_3)$, the pressure at each point is given by $P_2 = P_1(S_1/C_1 + 1)$ and $P_4 = P_1(S_1/C_{tot} + 1)$, S_1, S_2, and S_3 are the pumping speed at the corresponding point and C_{tot} is the total pumping conductance along the C_1-C_2-C_3 serial path as given by $C_{tot} = 1/C_1 + 1/C_2 + 1/C_3$. It is noticed that the pressure is inversely proportional to the pumping conductance. In the practical case of a 40- inch diagonal PDP panel, C_1 is 9.4×10^{-3} l/s for a tubular glass with an inner diameter of 2 mm and a length of 10 cm. C_2 is 2.37×10^{-4} l/s for a rectangular duct with a

'width by height' of '1.5 cm by 150 μm' and a length of 50 cm. In the case of C_3, the conducting path is considered to be a rectangular nozzle with a 'width by height' of '320 μm by 150 μm' and a length of 50 cm. Therefore, C_3 is 3.0×10^{-6}l/s. From these calculated values, we can see that the base vacuum level at the center of the panel is mainly limited by the pumping conductance of the rectangular nozzle given by the barrier ribs and the closely spaced glass plates. As a result, the P_4-to-P_2 ratio is approximately given by the C_1-to-C_3 ratio which corresponds to 3.1×10^{3}. Therefore, even though P_2 is 10^{-5} Torr, P_4 is only 3×10^{-2} Torr. If the base vacuum level is not low enough before gas filling, several impurities such as H_2, O_2, CO, CO_2, and N_2 will exist in the plasma gas. Theses impurities might increase the starting voltage of PDP and deteriorate the efficiency, thereby decreasing the lifetime. In order to avoid this problem, the vacuum level inside PDP panel before gas filling should be as good as possible. Furthermore, reducing the sealing process time is very important for a commercial product. The most probable method for obtaining the initial high vacuum level with a minimum sealing process time is a vacuum in-line technology which includes the sealing of the two glass plates within a high vacuum chamber, a filling with a plasma mixture gas, and finally hole-off. 'Hole-off' means plugging the tubeless hole in the rear glass plate and is used instead of the name 'tip-off' which is used in the conventional sealing process.

II. EXPERIMENTS

A panel is composed of two plates of soda-lime glass. The front glass plate has a size of 6 cm×9 cm and a thickness of 2.1 mm. The rear glass plate has a size of 7 cm×7 cm and a thickness 1.1mm. The active area in this experiment is 5 cm×5 cm and is defined by frit dispensing. The gap between two glass plates is about 0.5 mm or 0.2 mm sustained by small slices of Si or metal. However, it is not so easy to treat the frit glass in a vacuum environment because outgassing or vaporization phenomena occur severely during the heat up period, resulting in the bubbles, which become leak channels, inside the frit. The sealing procedure in this experiment is described below.

First of all, a sealing material of so-called frit paste is prepared by mixing a frit powder, which is mainly composed of PbO, ZnO, SiO_2, BaO etc., with a solvent including a binder material. The frit paste is dispensed along the edge of the front glass plate in atmosphere. Then, the dispensed frit is baked in a furnace in order to remove the solvent contained in the frit. The front glass plate with the preformed frit glass and the rear glass plate are loaded into a vacuum chamber, facing each other at some vertical distance. A high vacuum level is obtained by using a turbomolecular pump. The final vacuum level of the chamber is about 1×10^{-6} Torr. In order to seal the two panels, they should be heated up to about 300°C corresponding to the firing temperature of the preformed frit. During this heat-up cycle, severe outgassing or, in some case vaporization occurs, and the vacuum level decreases abruptly. The heat-up cycle should be precisely controlled in order to minimize these problems.

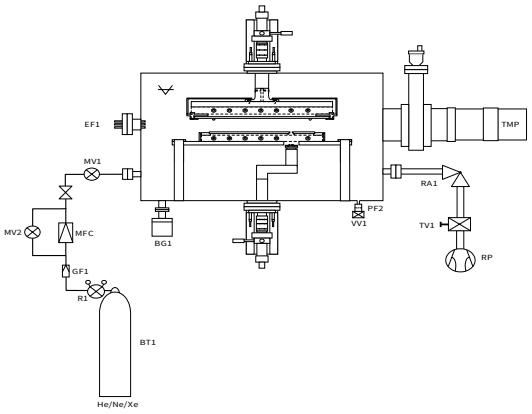


Fig. 3. Schematic diagram showing the vacuum in-line sealing technology.

Figure 3 shows the system for the vacuum in-line sealing including the heating stages and a plasma gas filling configuration. The heating of the two glass plates is done by using an infrared light source from a tungsten wire array. After arriving at the critical temperature, the two panels put into contact by using positional controls, that is, the upper glass plate is moved down via a x-y-z manipulator until it touches the lower glass plate. The manipulator gives a large enough press to seal the two plates. For a PDP panel, a plasma gas is introduced inside panel through a tubeless hole in the lower glass plate. After a given gas pressure is obtained, the hole is sealed-off by a locally heated frit. Then, the temperature decreases rapidly. After the cool down step, the panel is unloaded to complete the sealing process. In this experiment, we have tried to apply different types of frit materials in order to avoid the bubble problem.

With optimized unit process conditions, we fabricated a PDP panel with 2-inch diagonal active area. The front glass plate had 32×2 bus lines, including ITO electrodes, an insulation layer, and a MgO layer. The rear glass plate had 48×2 address lines interlaced under the barrier ribs and the green phosphor lines. It was driven by a 50-kHz AC pulses.

II. RESULT AND DISCUSSION

1. Material and Vacuum Characteristics

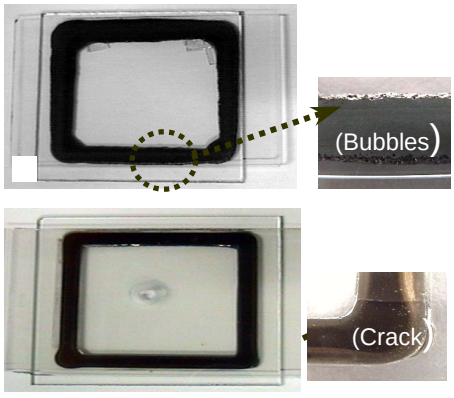
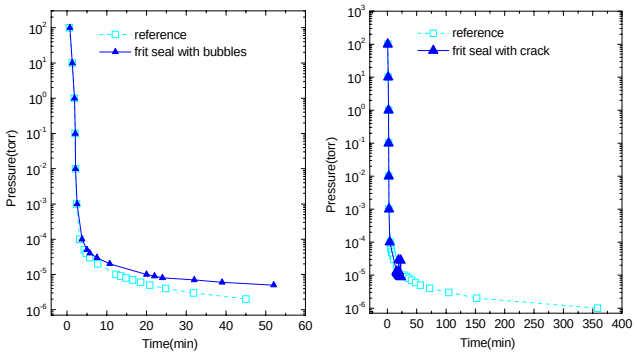


Fig. 4. Pictures showing a frit glass surface with (a) bubbles and

(b) a crack.

Figure 4 shows a camera view of the frit surface, bubbles appear in one type of commercial frit glass(type A) as shown in Fig.4(a), and some cracks appear in another type of frit glass (type B) as shown in Fig.4(b). We tested the leak rate for both cases and the results are shown in Fig.5. The leak test was done by pumping through an exhaust glass tube connected to the panel.



(a) (b)

Fig.5. Pump down rates for the panels sealed by using (a) the frit A suffering bubbles and (b) the frit B suffering cracks.

As shown in Fig.5 (a), the pump down rate in the case of the frit seal with suffering the bubbles was much slower than the reference pump down rate without the panel connection. In the case of the frit seal suffering some cracks as shown in Fig.5(b), a severe leak point occurred in the beginning of the pump down. In the previous papers[5, 6], we could evaluate the vacuum environment and contaminants inside the conventionally sealed panel indirectly by using the emission current measurement from a field emitter array.

In order to minimize the bubbles in the case of vacuum in-line sealing, we tried to form a new type of frit glass. The main reason for the bubbles seems to be vaporization of PbO molecules because the vapor pressure of the molecules increases exponentially with the vacuum level. In order to avoid the vaporization of PbO molecules, it is necessary to capture the molecules within the frit compound during the heating cycle. By using a new frit glass prepared by our own method, we were able to obtain a clean frit surface without bubbles or cracks, as shown in Fig. 6.

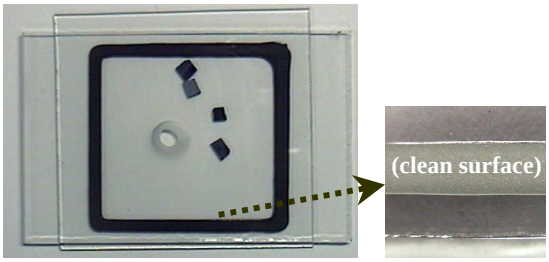


Fig. 6. Pictures showing a clean surface in a vacuum in-line sealed panel using a new frit prepared by our own method without bubbles.

For this vacuum in-line sealed panel, a leak test was performed using the same method as before, and the result was compared the reference pump rate without the panel connection. The results are shown in Fig. 7.

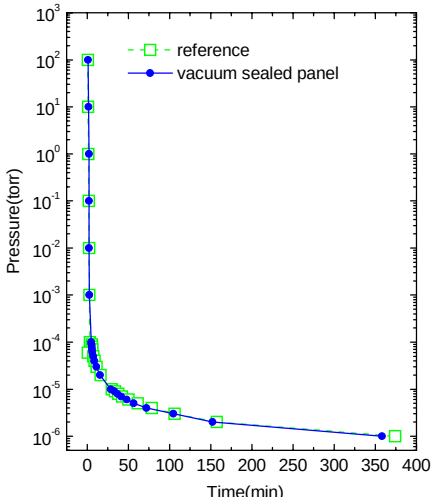


Fig. 7. Pump down rate for the vacuum in-line sealed panel without bubbles.

From the measurement, no leak was detected in the panel sealed by using the new frit glass and the vacuum in-line sealing technology. The SEM micrographs of cross-section of the vacuum sealed panel is shown in Fig. 8.

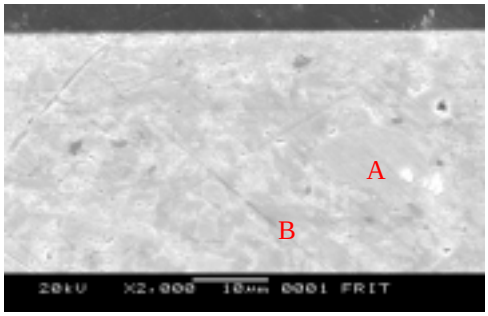


Fig. 8 The SEM micrographs of cross-section of the vacuum sealed panel showing a nucleated region A and an amorphous region B.

There was no noticeable bubbles or cracks in the bonded frit glass and the interfaces between glass plate and frit glass was relatively clean. In order to find out the factor for reducing the bubbles, we have performed EDS analysis through a magnified SEM picture. In the micrograph of the magnified SEM view shown in Fig. 8, there were shown two distinctive regions, that is, a nucleated region A and a randomly amorphous region B. The measured EDS graphs for each region are shown in Fig. 9. It is noticeable that titanium atoms were found in the nucleated region other than region B. We can expect that Ti atoms would help to progress the nucleation process during the sintering of the frit glass and subsequently, the nucleation process itself depress the bubbling phenomena via capturing some frit compounds such as PbO. The outgassing rate from the frit glass was prominent during the initial period of the heat-up cycle and disappeared rapidly after reaching a peak.

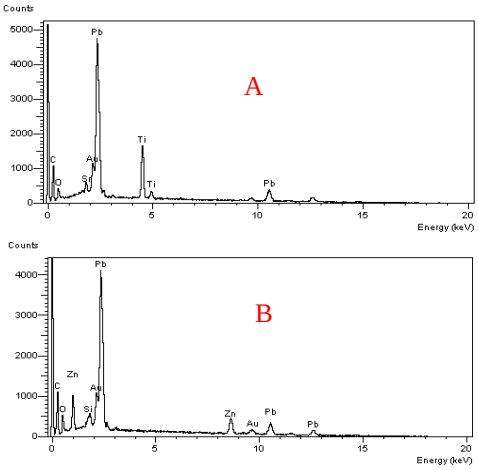


Fig. 9 EDS analysis in (a) a nucleated region A, and (b) an amorphous region B of the cross sectional frit surface.

2. PDP Panel Operation

We successfully fabricated a PDP panel with a 2-inch diagonal active area by using optimized vacuum in-line sealing technology for the first time in the world. The front glass plate is composed of ITO electrodes, bus electrodes of 32×2 lines, an insulation layer, and a MgO protection layer. The rear glass plate is composed of address electrodes of 48×2 lines, barrier ribs, and green phosphor lines. After loading two prepared glass plates inside the vacuum sealing process chamber, the sealing was done as following temperature cycle. The sealing temperature of the two plates was around 330°C which corresponded to a temperature about 120°C lower than that of the conventional sealing method in an air environment. The base vacuum level inside the panel at the point of the sealing time was about 5×10^{-6} Torr. After the sealing of the two plates, the panel temperature was reduced down to 270°C at a controlled heat-down rate, and subsequently, a Ne-Xe (4%) mixture gas was introduced inside the panel up to 400 Torr through a tubeless hole in the rear glass plate. After the plasma gas filling, a 'hole-off' process was done quickly by plugging the hole with a frit seal heated locally. After returning to room temperature, the PDP panel was unloaded from the chamber.

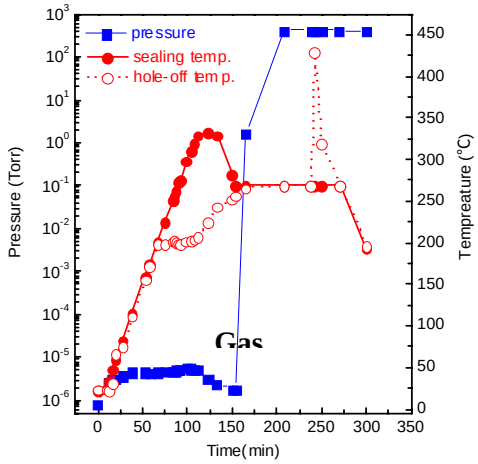


Fig. 10 Optimized whole temperature cycles for the vacuum in-line sealing of the PDP panel.

The optimized whole sealing cycles for the process was plotted in Fig.10 with the monitored pressure inside the panel. As shown, the total elapsed time for the vacuum in-line sealing process, including the temperature rise, the sealing of the two plates, the plasma gas filling, and hole-off, was less than 6 hours. The fabricated tubeless-type PDP panel is shown in Fig. 11.

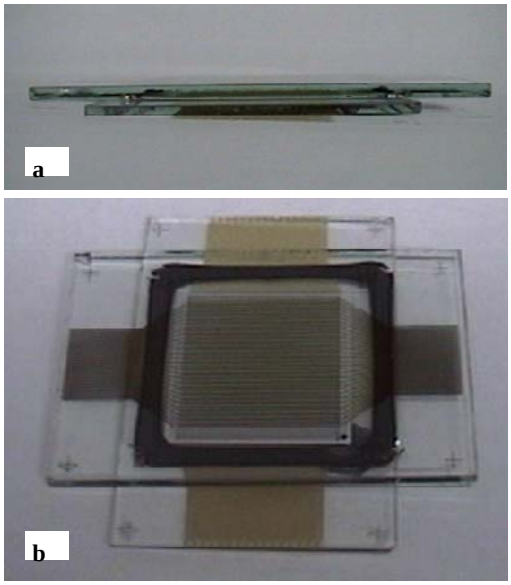


Fig. 11. Tubeless-type PDP panel sealed in a fully vacuum in-line sealing technology : (a) side-view and (b) front-view.

The panel was successfully operated with a starting voltage of 190 V driven by 50-kHz AC mode, resulting in a sufficiently high and uniform brightness at a sustaining voltage of 180V for all the pixels on the 2-inch diagonal active area, as shown in Fig. 12.

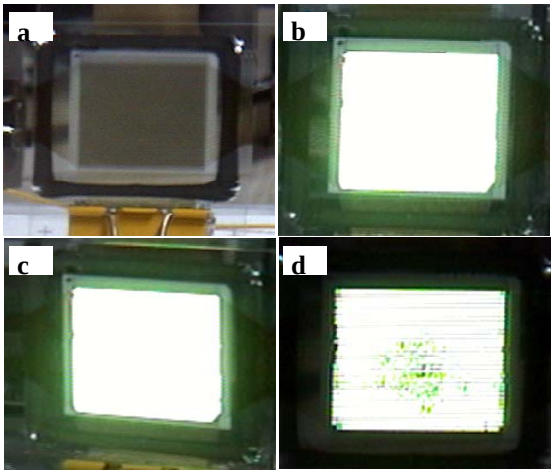


Fig. 12. Light emission from the vacuum in-line sealed PDP panel (a) at initial, (b) at a starting voltage of 190V, (c) at a sustaining voltage of 180V, and (d) at a minimum sustaining voltage of 140V. The operating frequency was 50kHz.

IV. CONCLUSION

In conclusion, we have tried to seal a PDP panel by using a vacuum in-line sealing technology. The sealing of the two glass plates composing the PDP panel, the plasma gas filling, and the hole-off process were done in a vacuum chamber. A prepared frit glass, which did not suffer from bubbles, was successfully used with the vacuum in-line sealing approach. We fabricated an operable 2-inch diagonal PDP panel by using the fully vacuum in-line sealing technology for first time in the world. The sealing temperature of the two plates was around 330°C which was 120°C lower than that in the conventional air environment. The base vacuum level inside the panel was about 5×10^{-6} Torr at the point of sealing, but before plasma gas filling. The hole-off time was negligible. Thus, the total elapsed time for the sealing processes was less than 6 hours, including gas fill and hole-off.

V. REFERENCES

[1] J. A. Castellano, Solid State Technology 41, 67(1998).
[2] B. R. Chalamala, Y. Wei, and B. E. Gnade, IEEE Spectrum 35, 42(1998).
[3] A. Roth, Vacuum technology(Publisher, city, year), Chap. 7, p.329
[4] C. Boffito and E. Sartorio, *Vacum Technik* 35, 212 (1986).
[5] S. J. Kwon, K. J. Hong, J. D. Lee, C. W. Oh, J. S. Yoo, and Y. B. Kwon. J. Vacuum and Science Technology(B), 18(3), 1227(2000).
[6] S. J. Kwon, K. S. Ryu, T. H. Cho, and J. D. Lee, J. Korean Phys. Soc. 33, S440 (1998).