# Tip-less PDP Vacuum In-Line Sealing Technology by Bubble-Reduced Frit along an Auxiliary Heating Line


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## ABSTRACT

*Sealing of two glass plates composing of PDP panel was done in a vacuum chamber by using an auxiliary heating line(AHL). In order to improve the uniformity of sealing temperature and reduce the panel temperature during sealing, the AHL was introduced by a screen printing method inside a frit glass and used as a part of heating source for the frit melting. By using the AHL technology and the specially prepared frit glass, we have successfully sealed a PDP test panel without bubbles and any leak through the frit glass.*


## 1. Introduction

In the conventional PDP fabrication processes, two glass plates, front and rear, are sealed using a frit glass in air atmosphere, followed by baking under pumping through an exhausting glass tube and filling with a plasma mixture gas, and finally tipped off. The base vacuum level to obtain in this sealing method is considerably limited because of the poor pumping conductance, which originated from the geometric panel configuration, closely spaced glass plates and barrier ribs [1]. The poor base vacuum level leaves the impurity gases such as $N_2$, $O_2$, $CO_2$, CO, $H_2$, inside the panel, which could increase the operational voltage, deteriorate the efficiency, and thereby decrease the lifetime. The long sealing time is one of the important obstacles to the PDP commercialization.

To overcome such problems in the conventional sealing process, we have recently proposed a vacuum in-line sealing technology[2, 3]. Two glass plates were sealed in a high vacuum chamber using the frit glass and plasma gas was introduced inside the panel through a tubeless hole in the rear glass plate. It was possible to reduce the sealing temperature from 450 °C to 330 °C, maintain the base vacuum level before gas filling about $5\times10^{-6}$ torr, and shorten the total sealing time less than 6 hours. The fully vacuum in-line sealing technology was successfully applied to 2-inch diagonal PDP panel[4,5] and a large scaled sealing system up to 20 inches is currently under development.

In this study, the feasibility of vacuum in-line sealing technology was further explored. To improve the uniformity of sealing and reduce the processing temperature further, an auxiliary heating line (AHL) was introduced inside the frit and used as a part of heating source for the frit melting. In fact, the PDP panel was successfully sealed at the chamber temperature of 250 °C with AHL and the base vacuum level maintained $10^{-6}$ torr without a leak.

## 2. Experimental Procedures

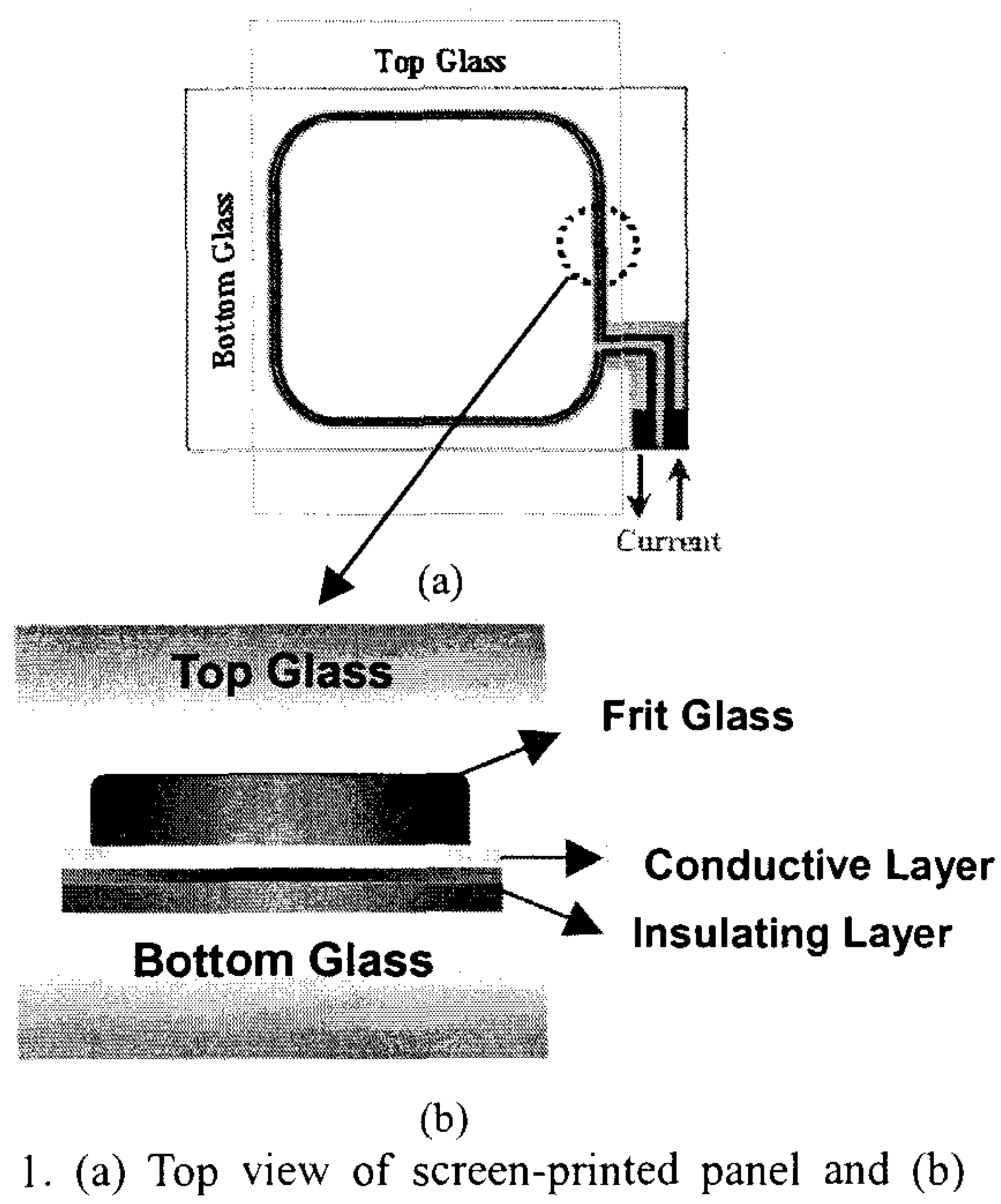



Fig. 1. (a) Top view of screen-printed panel and (b) side view of detailed structure of frit sealed panel for the vacuum in-line sealing.

A test panel consisted of two soda-lime-silica glass plates of 6×9×0.2 cm and the active area was 5×5 cm. After cleaning the plates, an insulating layer was screen-printed along the edge of the plate using frit glass (Fig. 1(a)) and baked in the furnace to burn out solvent and binder. The auxiliary heating line of a conductive layer was successively screen-printed on the insulating layer and baked (Fig. 1(b)). Then, the frit glass was dispensed on the AHL and fired at 380°C. The preformed bottom plate and top plate were loaded into the vacuum chamber and the electrodes were connected to the AHL. A high vacuum was obtained by using a turbomolecular pump and chamber temperature was controlled W-wire heater. When the chamber temperature reached 250°C under a vacuum, the current was started to flow in the AHL and raised until the frit glass was melted. At once the frit glass melted, the top plate was moved down via an x-y-z manipulator and it gave an enough force for two plates to be sealed. The distance between two glass plates was kept 200μm by a spacer such as slices of glass.

## 3. Results and Discussion

To find out the optimum sealing conditions using AHL in vacuum, the temperature profile with applied voltage to the AHL on the panel was determined by a thermocouple.

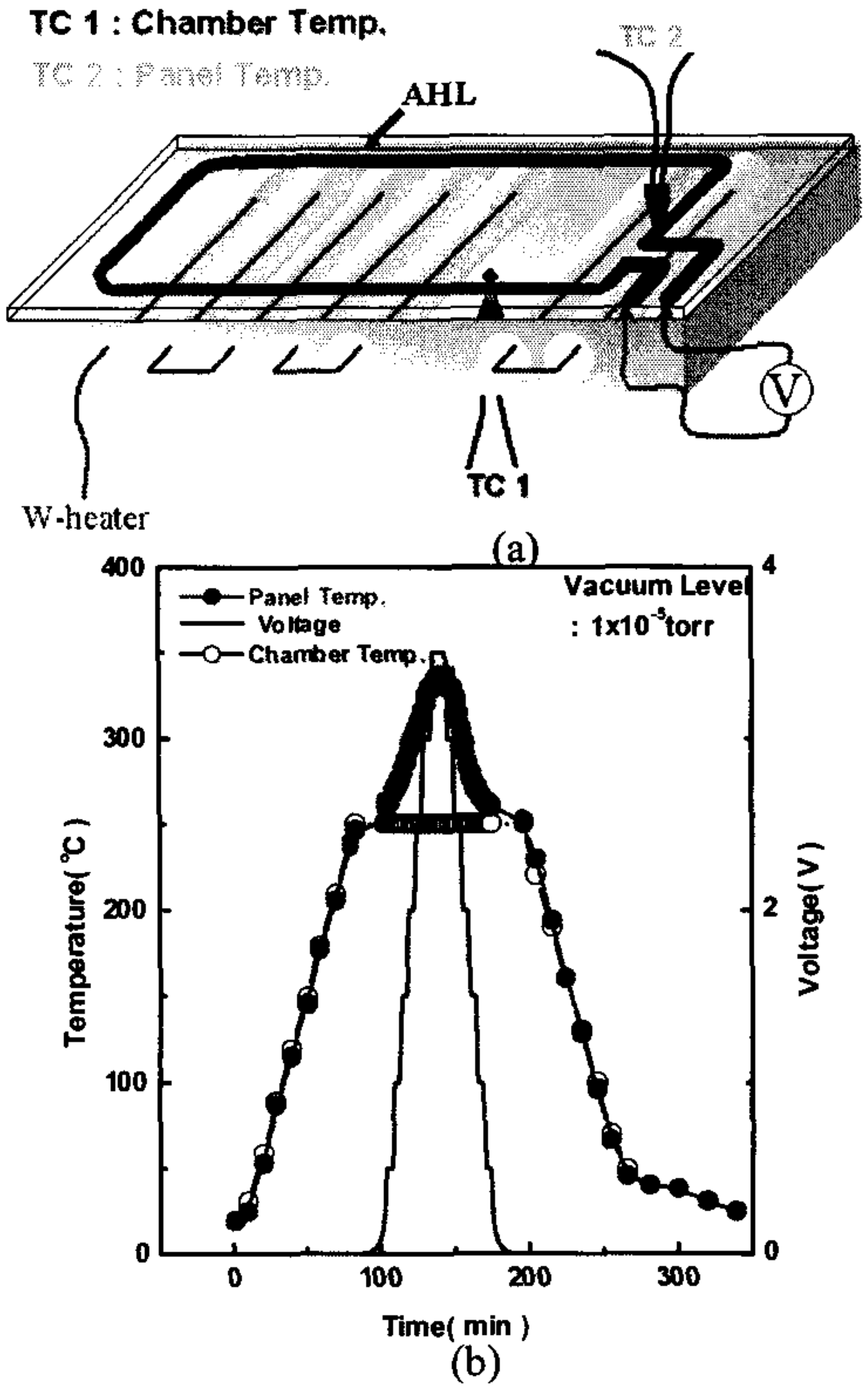



Fig. 2. (a) Position of thermocouples in the panel and (b) temperature profile of chamber and panel vs. applied voltage.

Figure 2(a) shows the positions of two thermocouples;one for vacuum chamber temperature control(TC1) and the other for the panel temperature monitoring on the AHL(TC2). The resultant panel temperature vs. applied voltage to AHL is shown in Fig. 2(b).

As mentioned before, due to a high vapor pressure of some components contained in a frit glass, bubbles occurs during heating cycle in the vacuum chamber. The chamber temperature was maintained at 250°C and the voltage was applied at the rate of 0.05 V/min. From the result, we can see that the local temperature along the heating line could be well controlled by applying the voltage without resulting the glass broken up to 370°C(~4.0V) under the chamber temperature of 250°C. At the voltage of 3.7 V, the local temperature on the AHL reached ~330°C, which was a proper temperature for a vacuum sealing reported from the previous results[4].

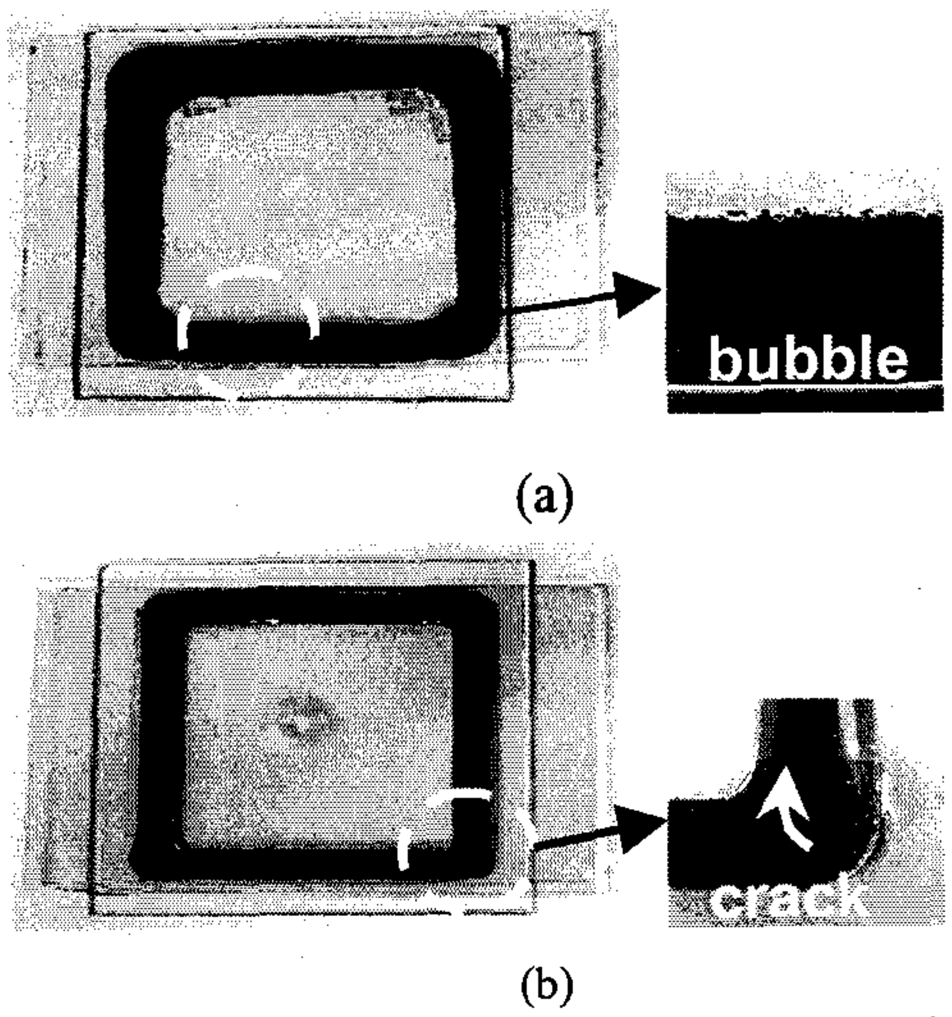



Fig. 3. Pictures showing frit glass surface resulting in (a) bubbles, and (b) crack.

As mentioned before, due to a high vapor pressure of some components contained in a frit glass, bubbles occurs during heating cycle in the vacuum chamber. Figure 3 shows the camera views of the frit surface, in which bubbles are appeared in one type of a commercial frit glass(type-A) as in Fig. 3(a) and some cracks in another type of frit glass(type-B) as in Fig. 3(b). In order to minimize the bubbles, we have tried to form a new type of frit glass. By using our own made frit glass, clean frit surface was obtained without bubbles and cracks, as shown in

Fig. 4. There were no bubbles and no cracks.

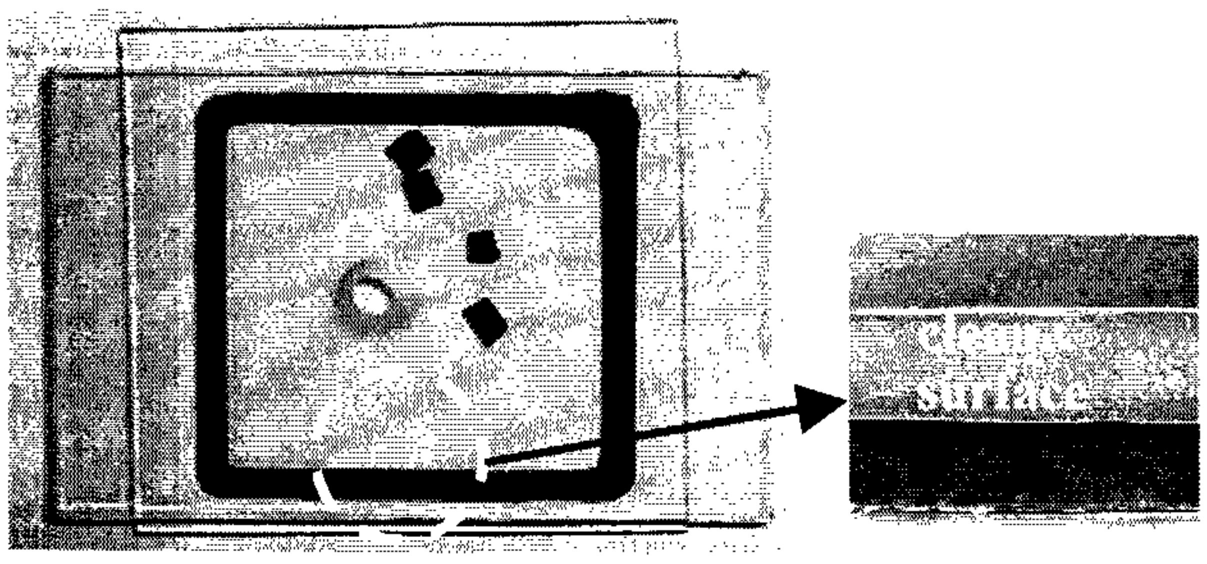
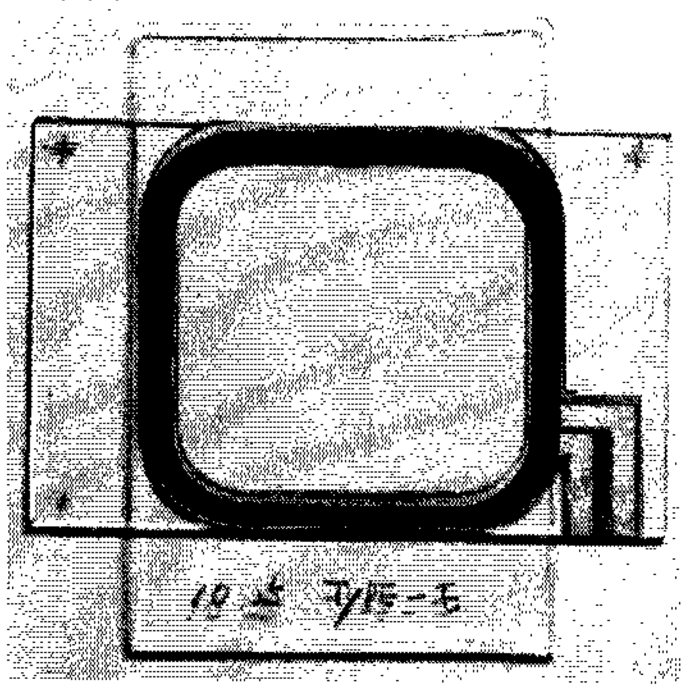



Fig. 4. Pictures showing a clean surface without bubbles for our own made frit glass.

We have performed the vacuum in-line sealing process of two glass plates by using the AHL technology and the specially prepared frit glass.

The top and side views of the sealed panel were shown in Fig. 5(a) and (b). In the vacuum sealing, there was a slight distance difference between chamber heater and panel, and the frit glass was melted completely when the applied voltage was 3.5V as shown in Fig. 6.



(a)

(b)

Fig. 5. (a) Top view and (b) side view of sealed panel.

The frit glass was completely melted and the sealed panel appears to be well bonded without cracks or bubbles, which used to be a serious problem in vacuum in-line sealing. The side view of panel indicated that the distance between two panels was uniformly maintained.

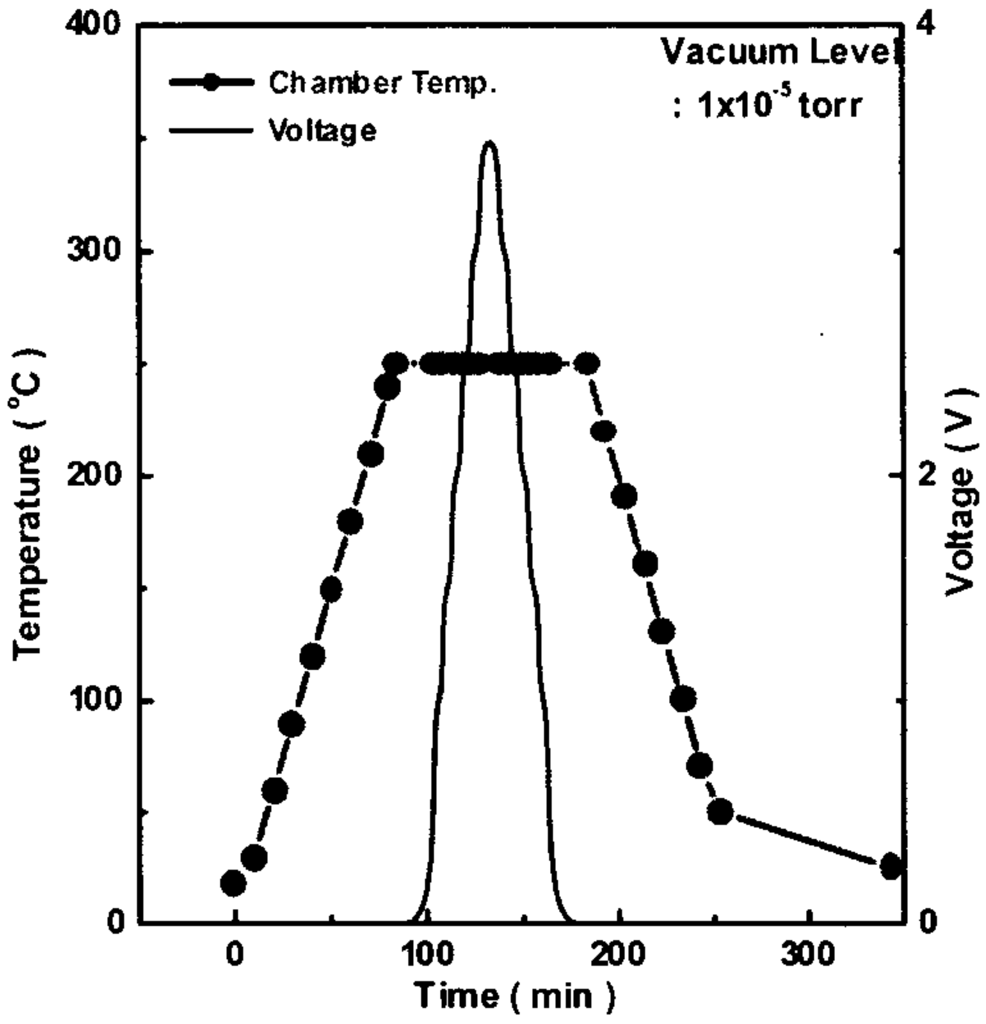
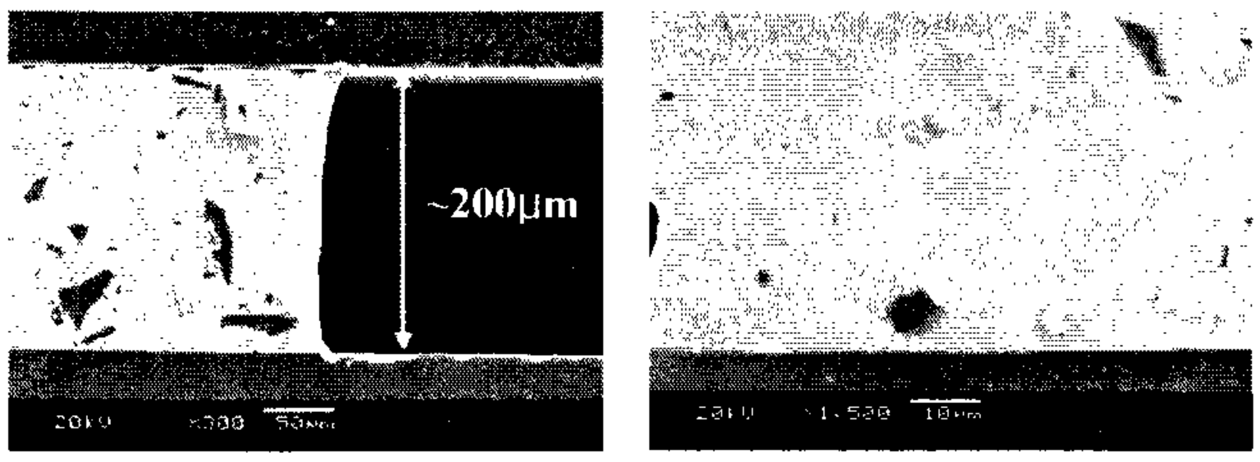



Fig. 6. Temperature profile of sealing.

The SEM micrographs of cross-section of the sealed panel are shown in Fig. 7. There were no noticeable bubbles or cracks in the bonded frit glass and the interfaces between glass plate and frit glass was relatively clean. The magnified micrograph of the preformed frit exhibited several small pores, but they were not interconnected each other and would not influence the vacuum inside the panel (Fig. 7(b)). The height of sealed panel was 200 μm throughout the panel, which guarantees the space for barrier ribs in PDP.

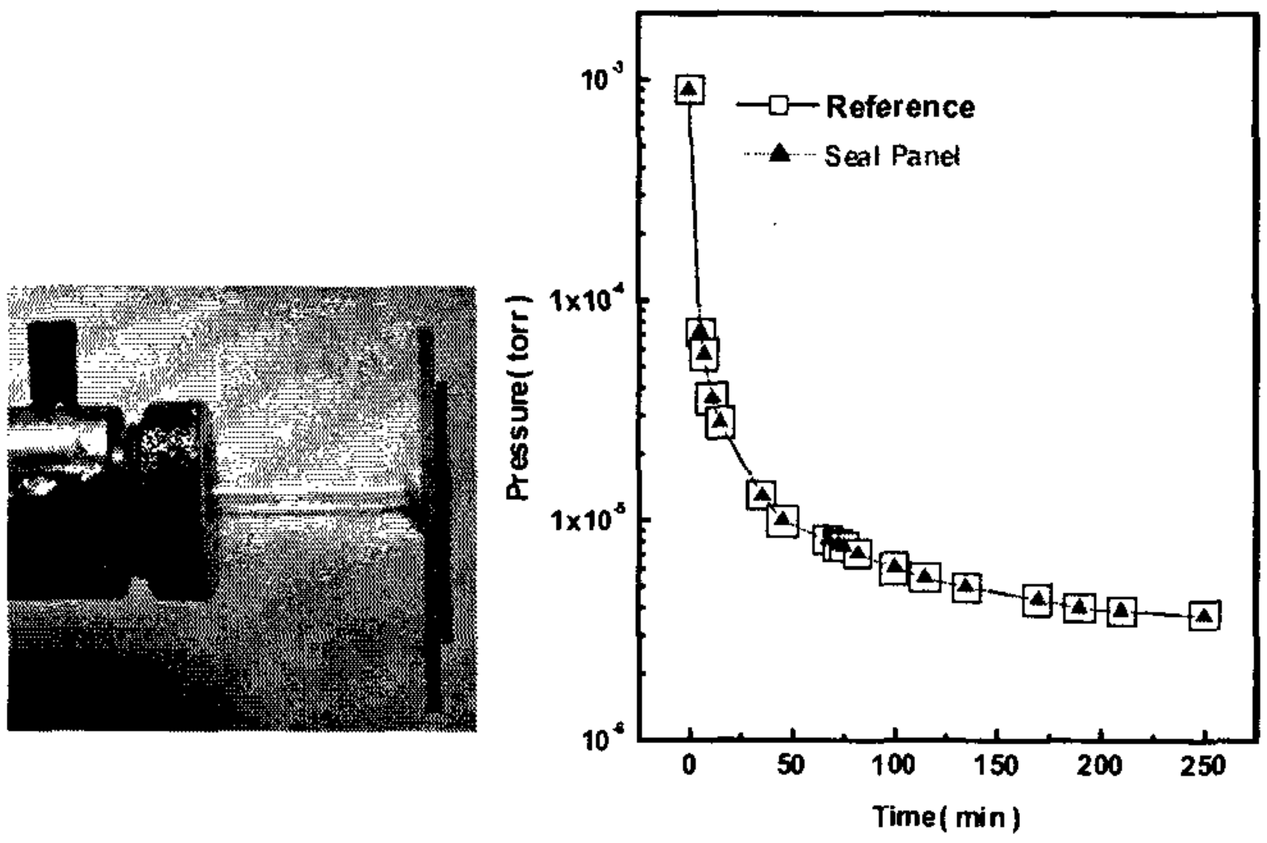
To confirm the sealing with AHL, the leak test was conducted by attaching the exhaust glass tube to the panel and pumping through it as shown in Fig.8(a). The pumping rate of the sealed panel was compared to that of reference without panel connection. The two pumping rates down to $10^{-6}$ torr were comparable as in Fig. 8(b).




(a) (b)

Fig. 7. (a) SEM cross-section of sealed panel, (b) magnified cross-sectional image.

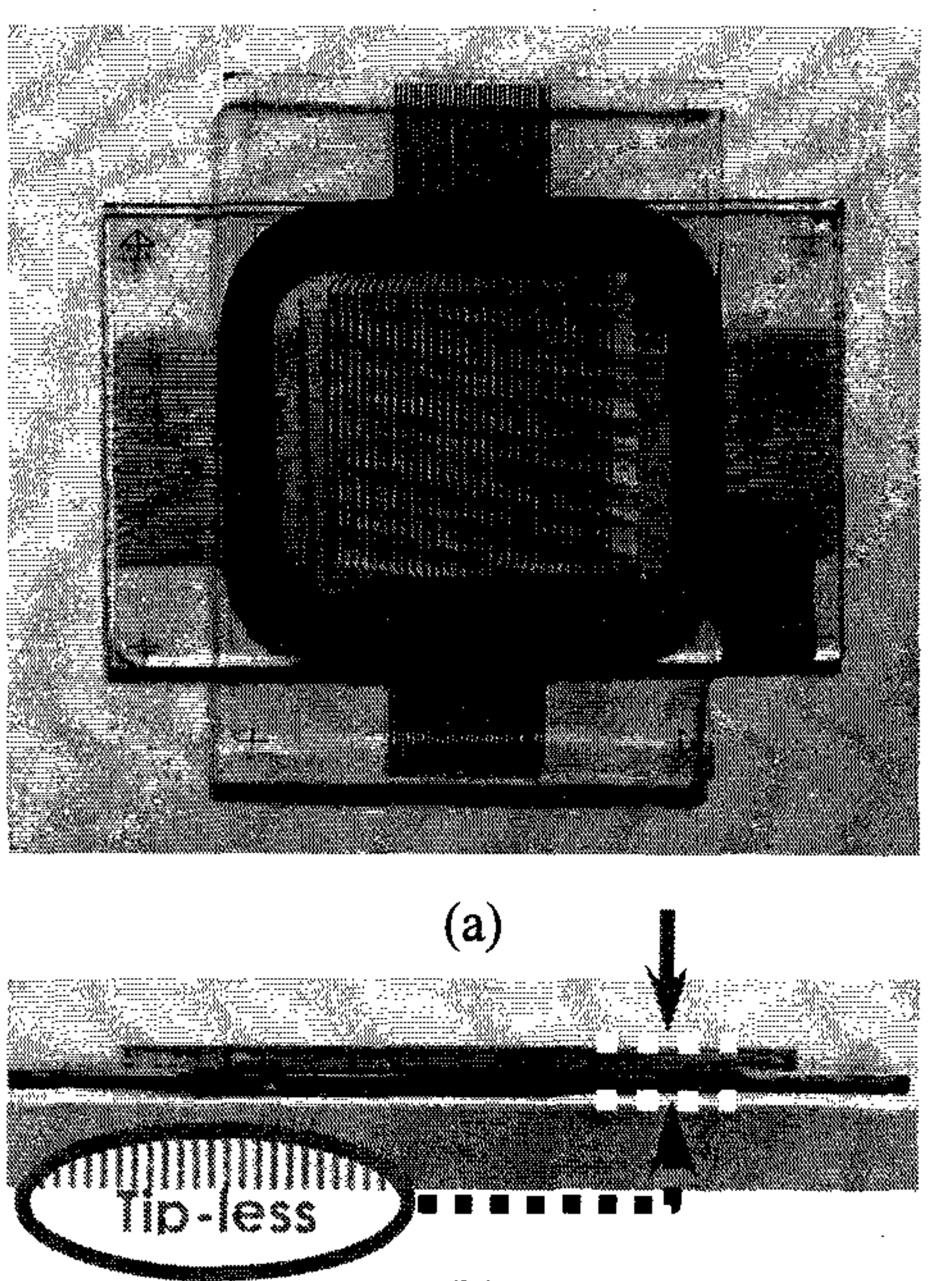
From the measurement, no leak was detected in the panel, which clearly indicated the feasibility of low temperature vacuum in-line sealing with AHL.




(a) (b)

Fig. 8. (a) Apparatus of a leak test and (b) vacuum profile with pumping time.

We successfully fabricated a PDP panel with a 2-inch diagonal active area using optimized vacuum in-line sealing technology. 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.

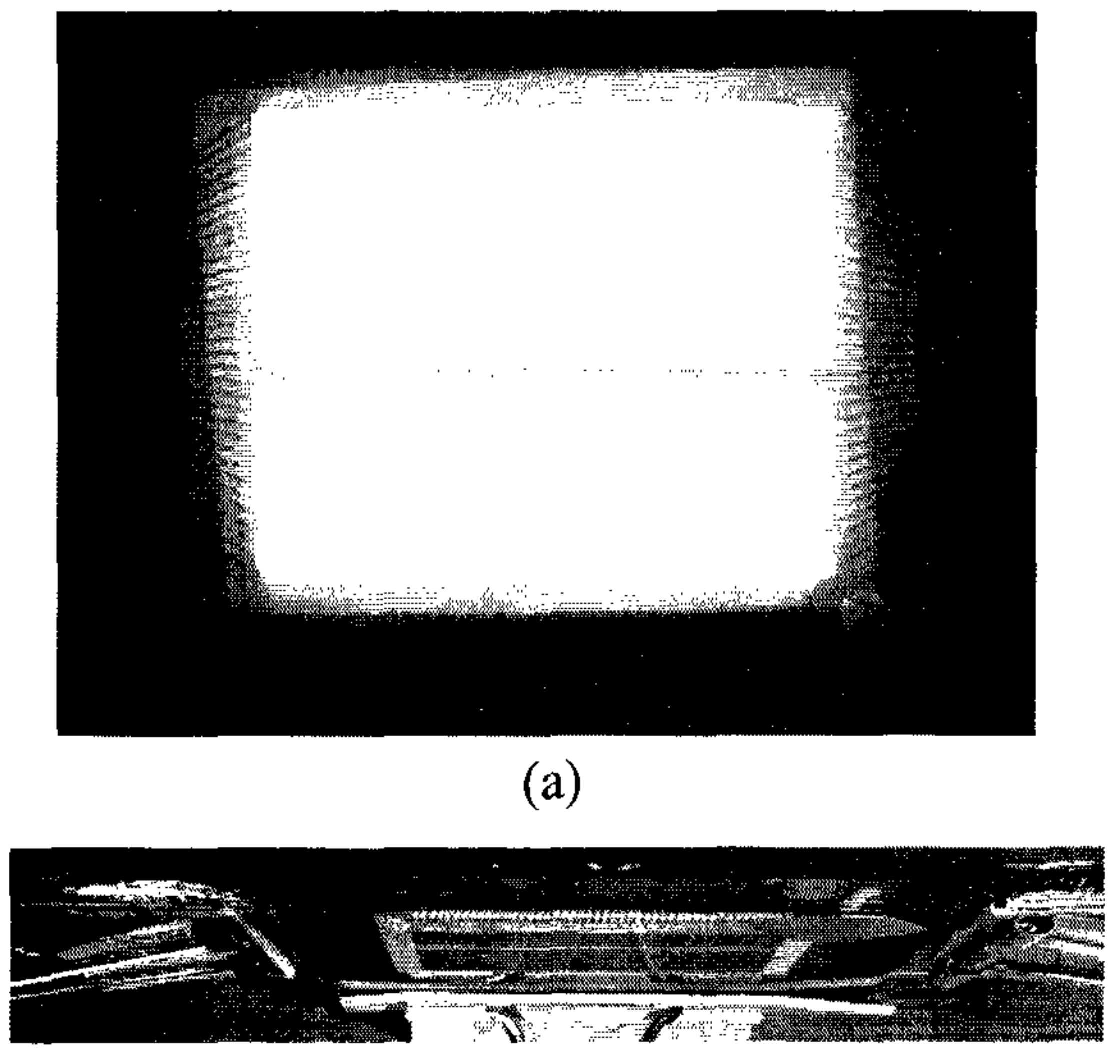



(a)

(b)

Fig. 9. An operational tubeless-type PDP panel sealed by using the auxiliary heating line in the vacuum : (a) front-view and (b) side-view.

The fabricated tubeless-type PDP panel is shown in Fig. 9. 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. 10.



(a)

(b)

Fig. 10. Light emission from the vacuum in-line sealed PDP panel by using AHL : (a) front view, and (b) rear-side view showing a tip-less sealing.

## 4. Summary

By applying a voltage to an auxiliary heating line, the resultant temperature along the AHL was well controlled. Final temperature was obtained up to 370 °C by the applied voltage of 4.0V without the glass plate broken while maintaining the chamber temperature at 250 °C. We have successfully sealed 2 inch PDP panel by applying 3.7V corresponding to 330 °C under the chamber temperature of 250 °C without bubbles and any leak through the frit glass.

## 5. References

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