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# Thin and Hermetic Packaging Process for Flat Panel Display Application

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## Abstract

This paper presents a study on the tubeless Plasma Display Panel (PDP) packaging using glass-to-glass electrostatic bonding with intermediate amorphous silicon. The bonded sample sealing the mixed gas with three species showed high strength ranging from 2.5 MPa to 4 MPa. The glass-to-glass bonding for packaging was performed at a low temperature of 180 °C by applying bias of 250 $V_{dc}$ in ambient of mixed gases of He-Ne(27 %)-Xe(3 %). The tubeless packaging was accomplished by bonding the support glass plate of 30 mm× 50 mm on the rear glass panel and the capping glass of 20 mm × 20 mm. The 4-inch color AC-PDP with thickness of 8 mm was successfully fabricated and fully emitted as white color at a firing voltage of 190V.

**Keywords** : PDP, tubeless packaging, electrostatic bonding, hermetic seal, light emission

## 1. Introduction

The color AC-PDP is one of the most promising display devices for a large-area flat panel display of over 40 inch wall-hanging TV. Compared with other displays, it has many potential advantages, such as simple structure, high resolution, large screen, fast response time, and broad view [1,2]. However, PDP is normally operated in gas ambient to generate the vacuum ultra violet (VUV) ray from xenon in the penning mixture gas [3]. In general, vacuum packaging of the PDP devices has been executed through an exhausting tube combined with the rear glass panel after gas injection like the cathode ray tube (CRT) method. This packaging method, however, has been proven to increase the thickness of the panel and to cause the out-gassing and metal oxidation by high temperature process, handling difficulty, and lower vacuum conductance due to the small inner volume [4,5]. Especially, the vacuum level of a PDP panel using CRT packaging method could be seriously affeeted by the out-gassing effect within the exhausting tube to be heated and melted in the tip-off process. Such out-gassing as CO and $CO_2$ generated due to the tip-off process causes firing or sustaining voltage to increase and affect the vacuum level of the panel and MgO film.

If the tube-based assemble process can be replaced with the tubeless packaging based on the electrostatic bonding technology, there will possibly be several technical advantages. The panel thickness can be reduced to 8mm~10mm by removing the exhausting tube of length of 25～30 mm and many problems by tip-off process can be solved. Also, such advanced technology without long exhausting tube will possibly make it easier

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to handle mass production. The vacuum packaging that uses glass-to-glass electrostatic bonding in the Field Emission Devices (FEDs), which requires a higher level of vacuum, has been reported to perform successful packaging [6].

In this paper, we applied the glass-to-glass bonding technology to the PDP packaging using silicon as an intermediate layer, as in the FEDs packaging, in order to attain an ideal hermetic seal. PDP tubeless packaging using the advanced bonding technology is expected to have many advantages such as simple process, gas uniformity, low temperature packaging, high vacuum efficiency, exhausting tube elimination, and reduction in pumping time.

## 2. Glass-to-glass Electrostatic Bonding

Electrostatic bonding was invented by G. Wallis and D. I Pomerantz in 1969, which was mainly focused on the bonding of Silicon-to-Pyrex #7740 glass [7, 8]. In general, the electrostatic bonding technique has been widely employed in SOI, microsensors, and micromechanical devices because of its simple process, relatively low temperature requirement, and high hermetic sealing capability [9-11].

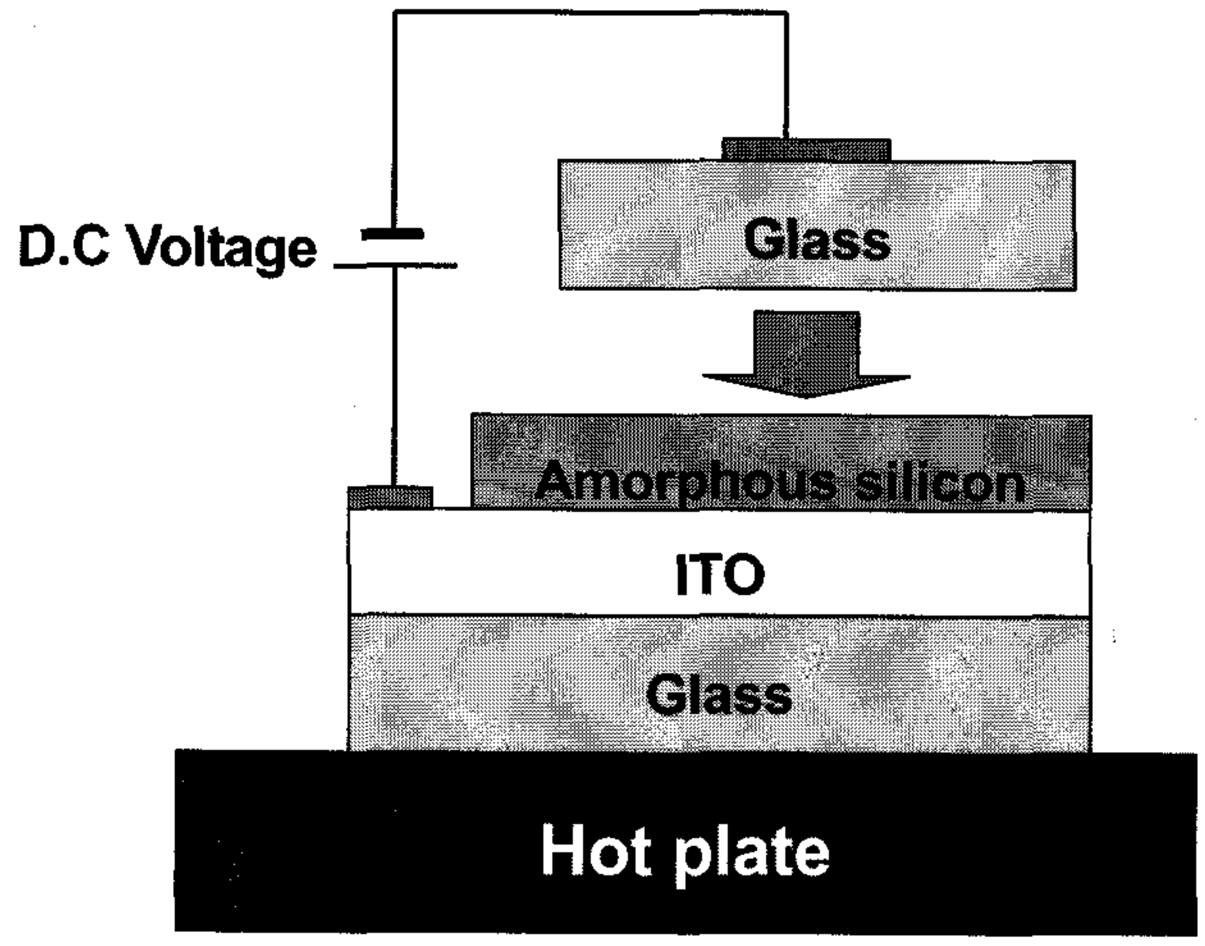


**Fig. 1.** Schematic diagram of the glass-to-glass bonding experimental set-up.

Fig. 1 shows the glass-to-glass bonding experimental set-up. The positive ions in glass materials were employed for electrostatic bonding with Si interlayer, which has the mobile carriers and the similar thermal expansion coefficient values comparable with the ones of glass interlayer. At elevated temperatures, the mobility of the positive sodium ions in the glass is fairly high, and the presence of an electric field causes them to migrate to the negatively charged cathode at the back of the glass wafer. As the $Na^+$ ions migrate towards the cathode, they leave a fixed charge in the glass that creates a high electrostatic field with a positive charge in the deposited amorphous silicon. As a consequence, the surfaces that contacted wafers are pulled together by the electrostatic force, and the atomic bond of Si-O-Si are presumed [12].

## 3. Experimental

In order to characterize the bonding process, current-time characteristics were measured with a Keithley 237 meter. The pull test for measuring the tensile strength of the bonded sample was performed. The cut surface of the bonded sample was observed with a scanning electron microscope (SEM).

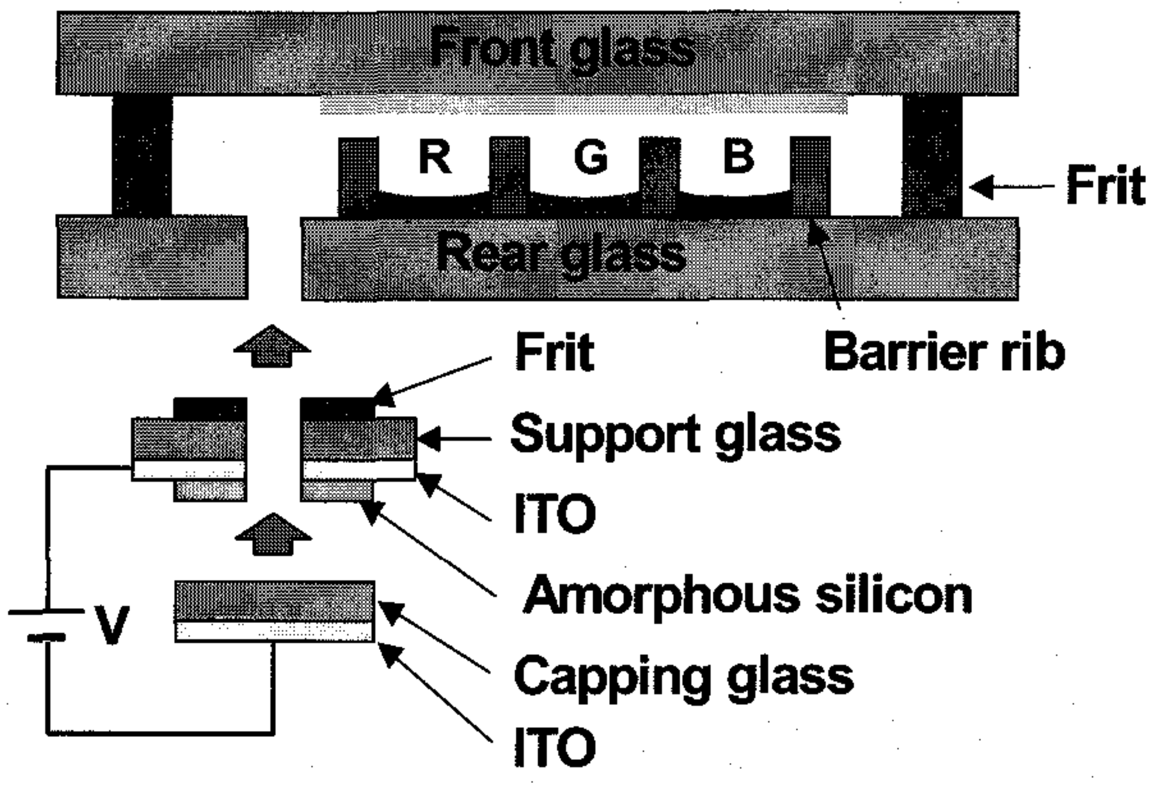
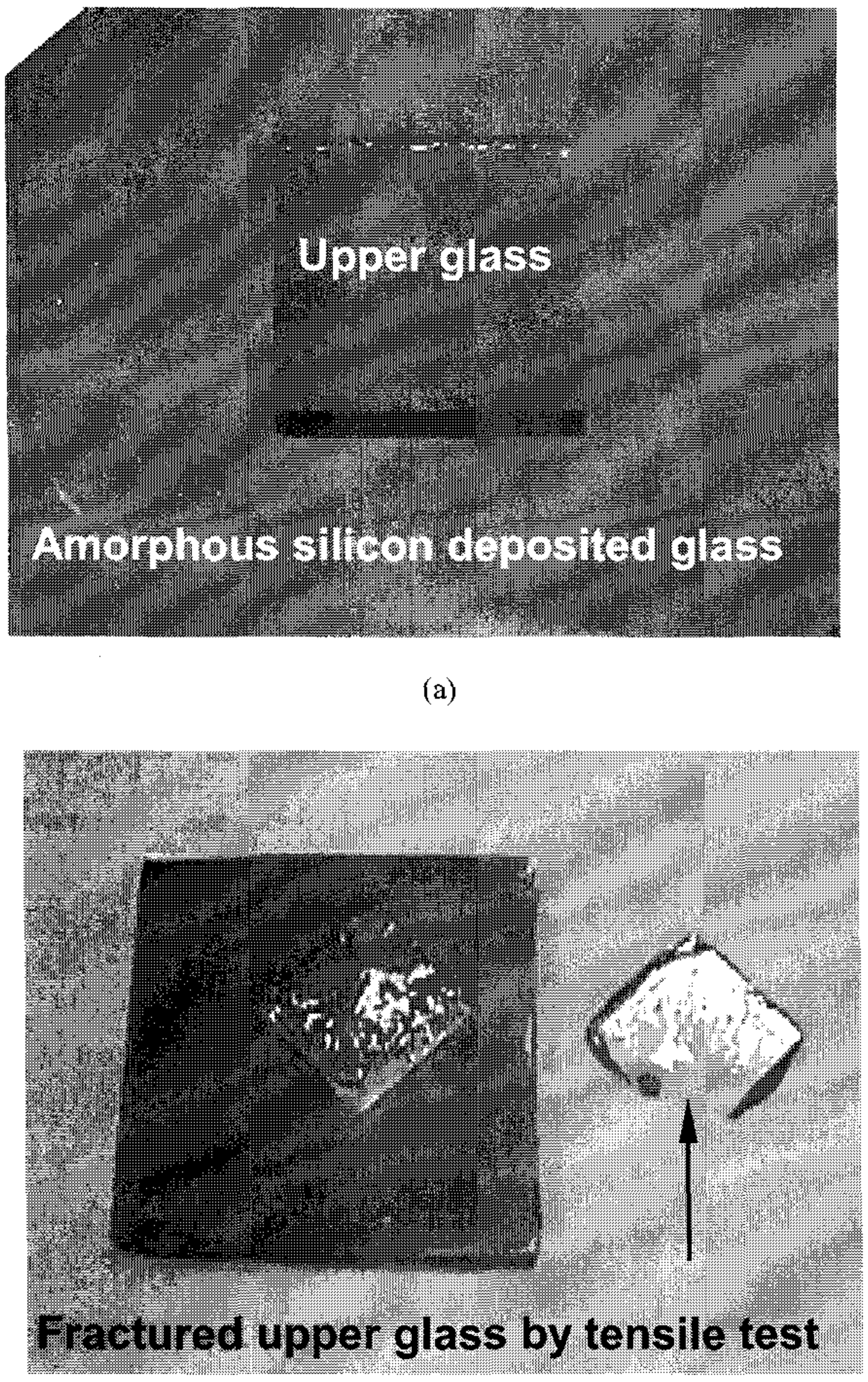


**Fig. 2.** Schematic diagram of the electrostatic bonding for the AC-PDP packaging.

The schematic diagram and electrical biasing are shown in Fig. 2. The sizes of the support glass plate and the capping glass were 30 mm×50 mm and 20 mm× 20 mm, respectively. The thin amorphous silicon film, 200 nm, was deposited at 120 ℃ by RF sputter on the ITO layer having a sheet resistance of 50 Ω/□. This sputtered ITO layer on the support glass plate provides contact and homogeneous electric field distribution during the electrostatic bonding process. After the frit glass was dispensed on the support glass, this glass was put on the rear glass panel and heated up to 420 ℃ so as to melt it in $N_2$ ambient. The panel was put in the vacuum chamber followed by pumping to $1\times10^{-6}$Torr. After annealing at 300 ℃, the mixed gas (He-Ne(27 %)-Xe(3 %)) was injected to 420 Torr through an open exhausting hole. If panel was cooled to room temperature, the inner pressure would reach 300 Torr. The capping glass had negative bias with respect to the silicon film on the support glass plate, and it was bonded at 180 ℃ by applying the bias of the dc voltage, 250 V. The tubeless packaged 4-inch color AC-PDP showed emission characteristics which is dependent on the driving voltage.



(a)

(b)

**Fig. 3.** Photograph of glass-to-glass bonded sample in gas ambient (a) and fractured sample by a tensile strength test (b).

## 4. Results and Discussion

Fig. 3 shows the photographs of the glass-to-glass sample bonded by electrostatic bonding in the mixed gas ambient (a) and the fractured sample by the pull tests (b). When the pull tests were performed to measure the tensile strength, fracturing was observed at the bulk region of the glass substrate or the interface region between the silicon layer and the ITO layer. In case fracturing occurs at the interface, the silicon layer is removed from the support glass plate. The bonding strength measured by the tensile strength method shows high strength ranging from 2.5 MPa to 4 MPa.

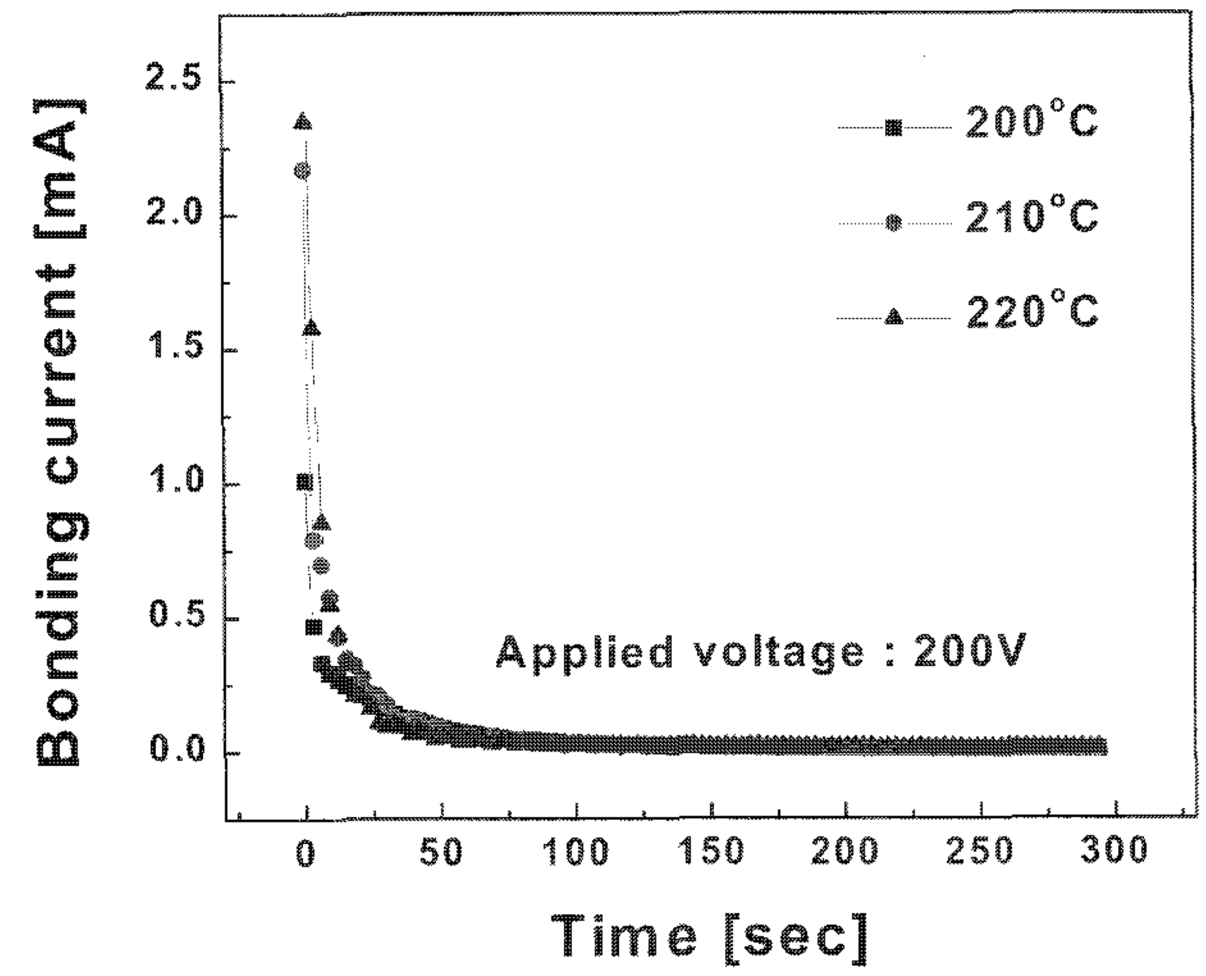


**Fig. 4.** Current characteristics as function of temperature variation.

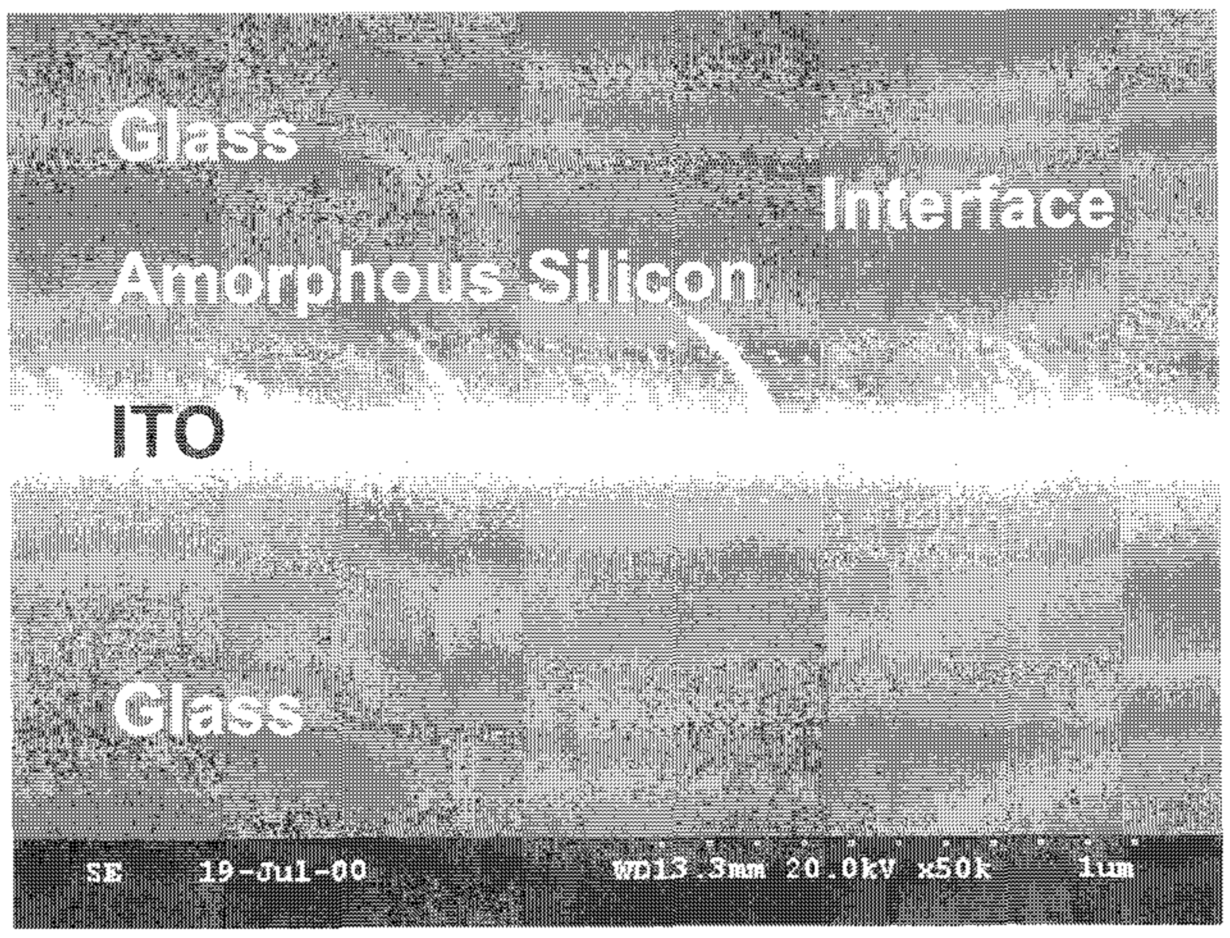


**Fig. 5.** Cross-sectional view of bonded interface by SEM.

The result of the measurement of the current-time characteristic with a Keithley 237 meter showed that, the bonding current rapidly decayed and then remained at the minimum level as shown in Fig. 4. The current profile was obtained well fitts with some typical current-time curves for electrostatic bonding. The bonding current was observed with the transport of sodium ions in the glass. High current density in this curve is desirable for enlarging the bonding area and for increasing the bonding strength.

Fig. 5 shows the cross-sectional photographs by SEM. The bonded interface region between the amorphous silicon layer on the ITO layer and the capping glass was very smooth and clearly defined.

When the bias of 250 V for tubeless packaging was applied at a temperature of 180 ℃, the capping glass was bonded to the support glass. The capping glass hasd negative bias with respect to the silicon film on the support glass plate. At elevated temperatures, the mobility of the positive sodium ions in the capping glass plate was fairly high and the presence of an electric field causes them to migrate to the negatively charged cathode at the back of the capping glass plate. As the $Na^+$ ions migrate towards the cathode, they leave a fixed charge in the glass creating a high electrostatic field with a positive charge in the deposited amorphous silicon. The bonding with an open exhausting hole was successfully executed with electrostatic bonding.

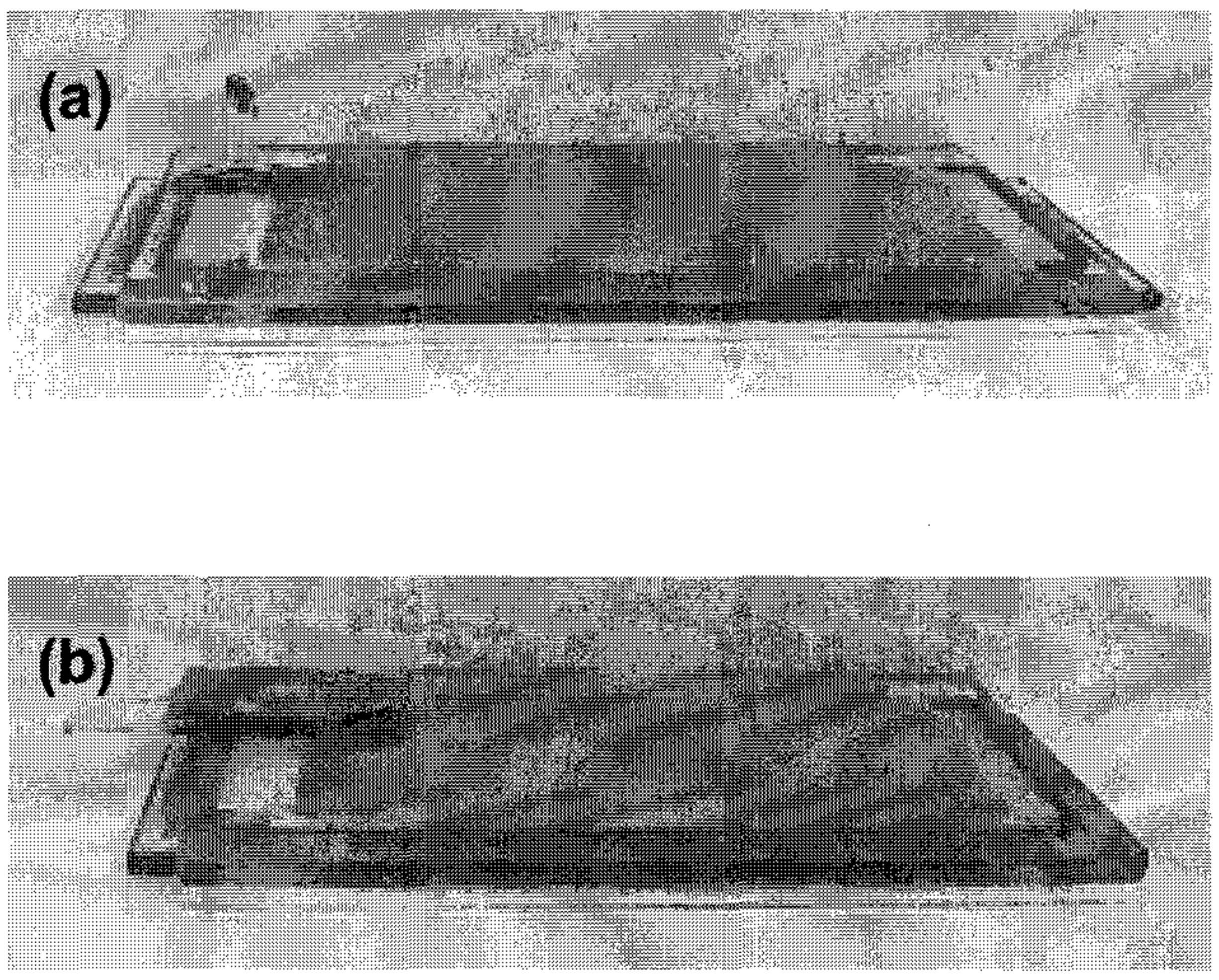


**Fig. 6.** Comparison of packaged panel by conventional tip-off method (a), and by glass-to-glass bonding method (b).

Fig. 6(a) shows the photograph of the panel packaged by the tip-off process using the conventional method, and Fig. 6(b) shows the packaged panel whose thickness is 8mm by the electrostatic bonding method without a tube. As shown in this figure, the panel by the tubeless packaging is much thinner than that by the tip-off packaging. The proposed technology causes problem of consumption of mixed gas, but this problem can be solved by applying gas injection system. This system for the vacuum in-line system has already been reported and we referred the paper[13]. Furthermore, this method will possibly make it easier to handling for mass production.

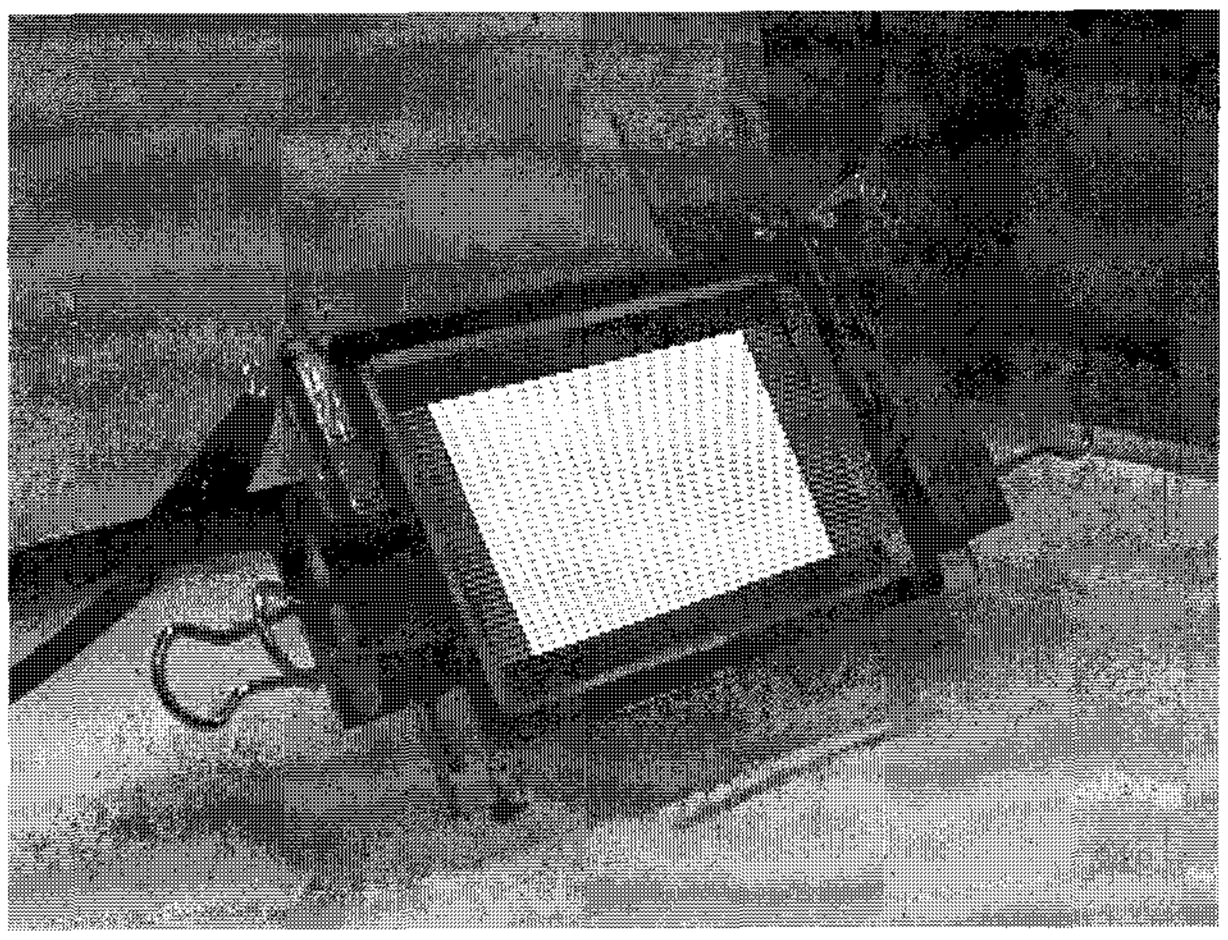


**Fig. 7.** Photograph the whole body of the tubeless packaged AC-PDP emitting stable.

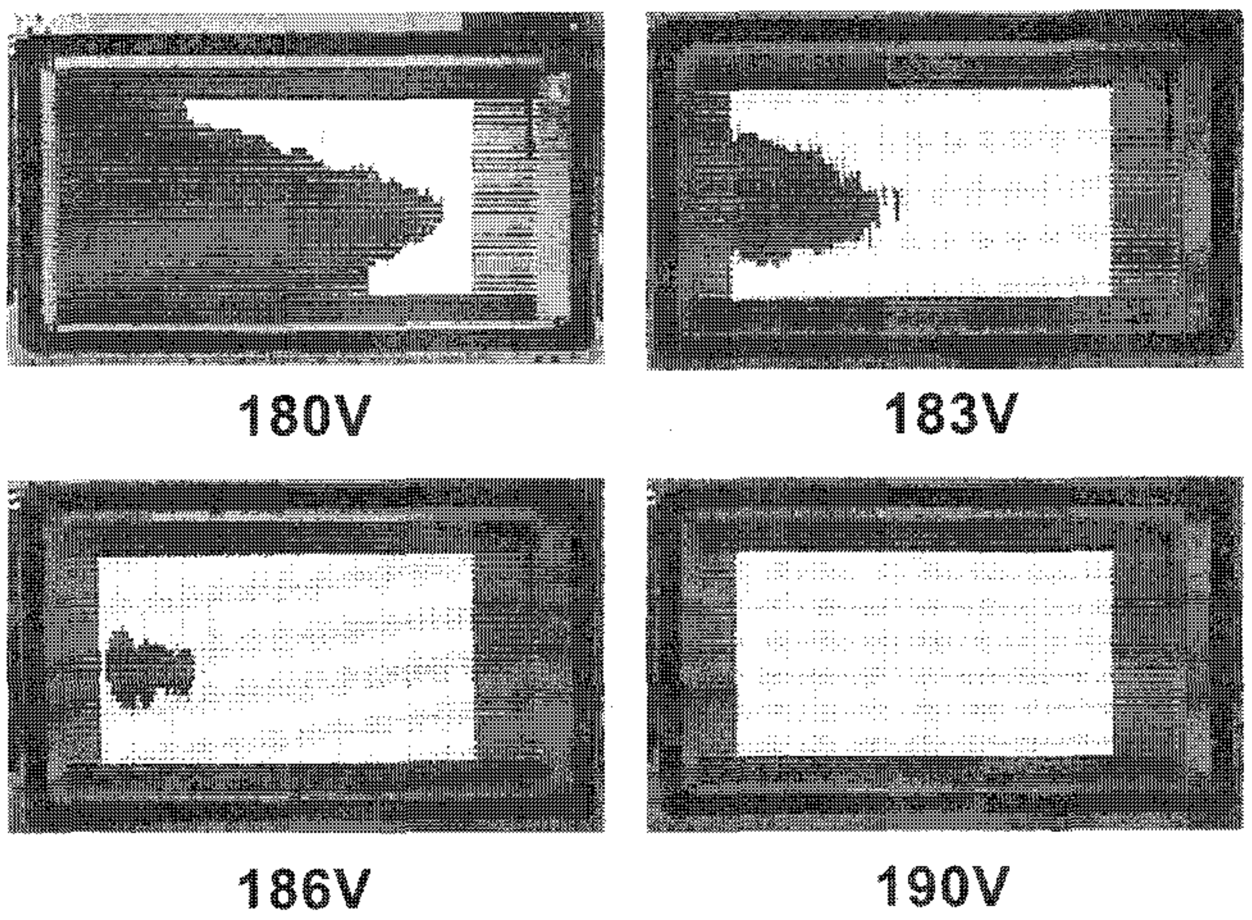


**Fig. 8.** Emission characteristic as function of a driving voltage.

Fig. 7 shows the whole body of the tubeless packaged AC-PDP emitting system. Fig. 8 shows the emission characteristics as a function of the driving voltage of the tubeless packaged 4-inch color AC-PDP. The full light emission of the 4-inch color AC-PDP was accomplished. Fig. 9 shows a backside photograph of the tubeless packaged AC-PDP by the electrostatic bonding method. Fig. 10 shows the variations of firing and sustaining voltage during the aging time. The aging of AC-PDP was executed for 25 hours, and its maximum firing voltage was 230 V with a driving freguenay of 50 KHz without address voltage. After the aging during 25 hours, full light emission of the 4-inch PDP panel was emitted at 190 V.

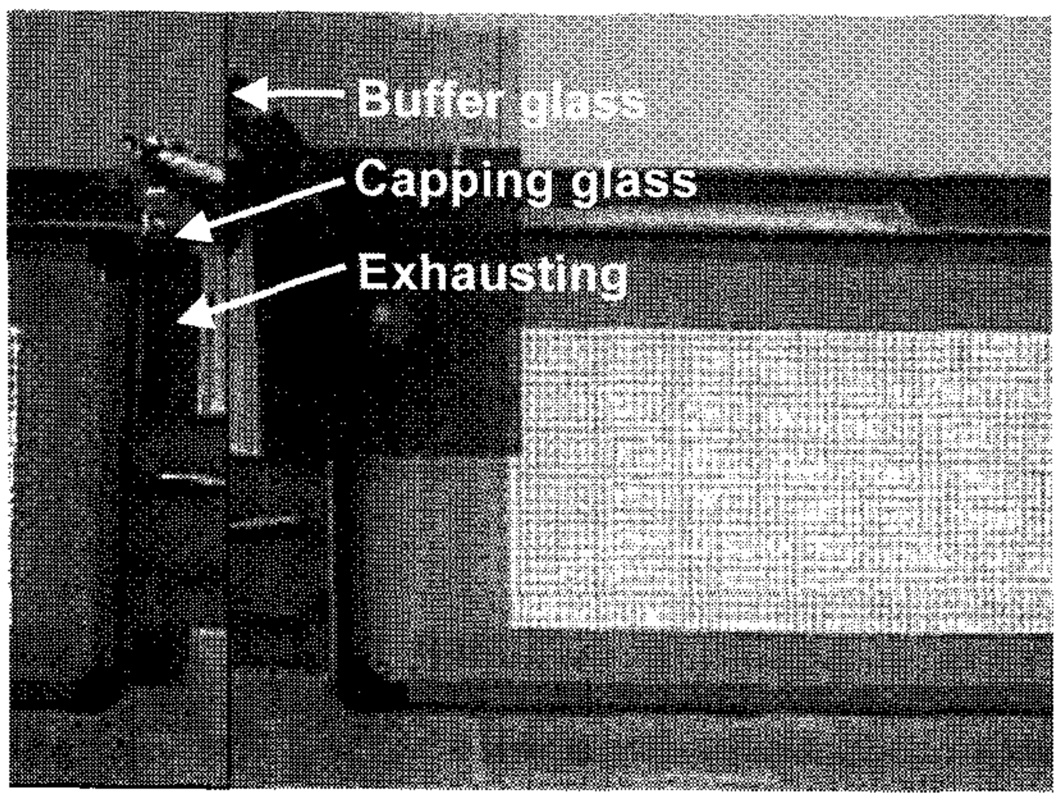


**Fig. 9.** Backview photograph of glass-to-glass electrostatic bonding.

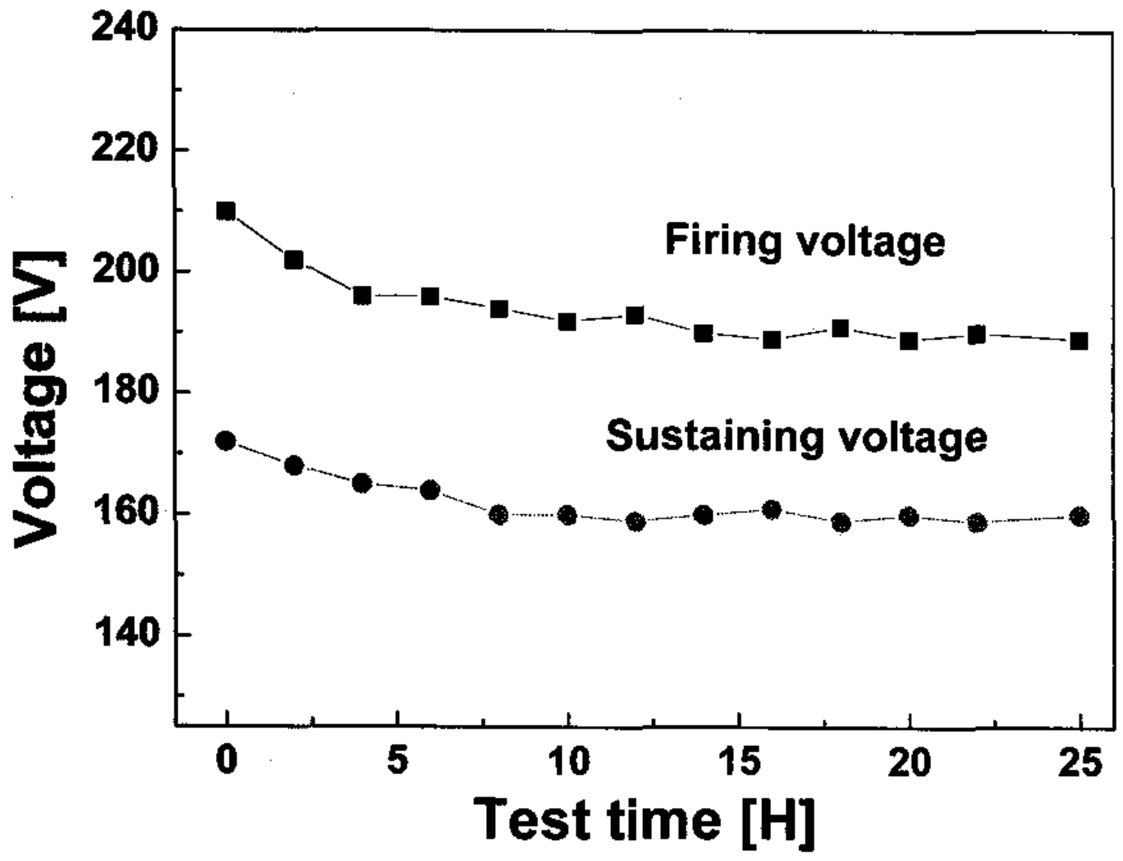


**Fig. 10.** Variations of firing and sustaining voltage for aging time.

PDP tubeless packaging using glass-to-glass electrostatic bonding was successfully executed as 8mm thickness, at a low temperature of 180 ℃, and 250 V bias application.

## 5. Conclusion

PDP tubeless packaging using glass-to-glass electrostatic bonding with intermediate amorphous silicon layer was completed at 180 ℃ and with the bias of 250 V after injecting the mixed gas (He-Ne(27 %)-Xe(3 %)). In this study, we used the support glass plate sputtering ITO/Si layer. The glass side of the support glass plate is bonded to the rear glass panel with the frit glass in PDP, and the silicon side of this plate is bonded to the capping glass by the electrostatic bonding method after the mixed gas injection. The bonding strength in this study is almost like a bulk region (2.5 ~ 4 MPa). The current-time characteristic curve was fitted with some typical case for electrostatic bonding, and the bonded interface region was very smooth and clearly defined. After the sealing process by the electrostatic process in the mixed gas ambient, the aging of AC-PDP was executed for 25 hours. The full light emission of 4-inch color AC-PDP was successfully obtained at low temperature of 180 °C and by applying bias 250 $V_{dc}$. If the tube-based assemble process can be replaced with the tubeless packaging based on the electrostatic bonding technology, the panel thickness can be reduced to 8 ~ 10 mm by removing 25~30 mm of the exhausting tube. Also, this advanced technology will make it easier to handle the mass production of AC-PDP fabrication process.

## References

[ 1 ] T. Nakamura, K. Lseki, Y. Sano, and K. Nunomura, SID'95 Digest, 807 (1995).

[ 2 ] T. Hirose, K. Kariya, M. Wakitani, and A. Otsuka, SID'96 Digest, 279 (1996).

[ 3 ] M. Kamiya, H. Uchiike, T. Sasaki, and Y. Kawai, Asia Display'95 Digest, 385 (1995).

[ 4 ] S. J. Jung, G. J. Moon, K. S. Kim, M.S. kim, K. J. Woo, N. Y. Lee, and S.Y.Ahn, Asia Display'98 Digest, 1157 (1998).

[ 5 ] A. Roth, Vacuum Sealing Technique(AIP press, New york 1994), p. 228.

[ 6 ] W. B. Choi, B. K. Ju, Y. H. Lee, J. W. Jeong, and M. H. Oh, SID'98 Digest, 593 (1998).

[ 7 ] G. Wallis and D. I. Pomerantz J. Appl. Phys, **40**, 3946 (1996).

[ 8 ] C. D. Fung, P. W. Cheung, W. H. Ko, and D. G. Fleming, Elsevier Science, (Amsterdam, 1985) p. 41.

[ 9 ] A. D. Kurtz, J. R. Mallon, and H. Bernstein, ISA ASI 73246, 229 (1973).

[ 10 ] L. M. Roylance and J. B. Angell, IEEE Trans. Electron Devices, 1911, **ED-26** (1979).

[ 11 ] S. C. Terry, J. H. Jerman, and J. B. Angell, IEEE Trans.

Electron Device, **ED-26** 1880 (1979).
[ 12 ] J. B. Lasky, S. R. Stiffer, F. R. White, and J. R. Abernathy, Tech. Digest, IEEE Int. Electron Devices Meet., Washington, DC, U.S.A.,**28**, 684 (1985).
[ 13 ] H. S. Kim, G. S. Chui, and J. H. Lee, Proceedings of the 1'st Plasma Display Workshop'200, 29 (2000).