Vacuum In-line Sealing Technology of the Screen-printed CNT-FEA

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Abstract

We have fabricated a carbon nanotube field emission display (CNT-FED) panel with a 2-inch diagonal size by using a screen printing method and vacuum in-line sealing technology. The sealing temperature of the panel was around 390 °C and the vacuum level was obtained with 1.4×10^{-5}torr at the sealing. When the field emission properties of a fabricated and sealed CNT-FED panel were characterized and compared with those of the unsealed panel which was located in a test chamber of vacuum level similar with the sealed panel. As a result, the sealed panel showed similar I-V characteristics with unsealed one and uniform light emission with very high brightness at a current density of 243 $\mu A/cm^2$, obtained at the electric field of 10 V/μm.

Keywords : carbon nanotube, FED, sealing, screen Printing

1. Introduction

Field emission display (FED) has been generally described as a device having CRT-like image qualities and low power consumption and has been expected to be a candidate for large-size flat panel display. Therefore, it is important to find the most cost-effective method of producing FED panels with large screen size. CNT has become the most promising candidate as an electron emitting source due to its low work function, chemical and physical stability. Among the various fabrication technologies of CNT-emitters, the screen printing can be most cost-effective method because the method can be applied easily to a large screen size and has become a well mature technology in other display manufacturing areas. The field emission characteristics of FED is mainly dependent on the vacuum level inside the sealed panel[1]. Moreover, the vacuum environment affects the lifetime of the field emitters dominantly. Therefore, the high vacuum sealing is one of the most important technologies in commercializing FED. However, in the conventional sealing method, which is also referred to as 'a tubulation method' because of it is pumped through an evacuation tube sealed to the panel, the sealing process time is too long and several process steps are involved, for example, a front glass sealing to a rear glass, a long tube sealing to the rear glass, pumping through the glass tube, and a tip-off, etc., All these processes require a high temperature cycle. The long process time and the fact that it involves many process steps are factors that incease the FED fabrication cost and reducing yield. Besides the process-related problems, the obtainable base vacuum level is limited by the pumping conductance which is mainly attributed from the pumping conductance of the long glass tube and the closely spaced glass plates including the complicated structure of the gated-emitters[2-4]. In addition, sustaining an initial high vacuum level is also important

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against the outgassing from several components consisting the FED[5, 6]. The most probable method for obtaining the initial high vacuum level with a minimum sealing process time is the vacuum in-line sealing technology which consists of the sealing of two glass plates within a high vacuum chamber and finally tip-less hole-off.

We have tried to apply a vacuum in-line sealing technology to a CNT-FEA formed on soda-lime glass substrate having an active area of 2 inch diagonal size and fabricated by a screen printing method. In this paper, we propose a fabrication and sealing process of the diode type CNT-FED.

2. Experimental Procedures

In this study, we have prepared CNT-paste by dispersing a plurality of needle-like carbon nanotubes in a conductive viscous solution. The carbon nanotube was a fully graphitized cylinder having a diameter about a few tenth of a nm and a length in 1 to a few μm. The carbon nanotubes were obtained by an arc-discharging technology. The conductive CNT-paste were prepared by dispersing silver particles in a vehicle in addition to low softening point frit glass particles as a fixing binder. The vehicle was a viscous liquid in which a resin, typically ethyl cellulose, and has excellent heating decomposability and volatility was dissolved in a solvent, typically terpineol. By combining the CNT-paste with photo-sensitive resist, the paste could be patterned by using a photolithography technology. The patterned CNT electron emitters were formed on the glass substrate. An anode glass plate having a phosphor screen were faced to the electron-emitting source in order to constitute the vacuum fluorescent display apparatus, so called CNT-FED. Electrons emitted by the CNT electron-emitting source were bombarded against the phosphor layer, producing cathodoluminescent light emission. In a diode FED structure as implemented in this study, the anode was used as an extraction electrode.

Fig. 1 shows a schematic diagram of diode type CNT-FED panel with 2 inch diagonal size. The panel is composed of two plates of soda-lime glass. The front glass plate has a size of 7 cm × 9 cm and a thickness of 1.8 mm. The rear glass plate has a size of 7 cm × 8 cm and a thickness of 1.8 mm. The active area in this experiment is 3.5 cm × 3.5 cm.

Fig. 2 shows the fabrication sequences of the vacuum in-line sealed CNT-FED in our experiment. First, the CNT-FEA plate was fabricated by a screen printing method using CNT powder mixed paste. Then, the anode plate was prepared with a patterned ITO electrode. Finally, two plates were sealed by using a dispensed frit glass paste within the high vacuum chamber.

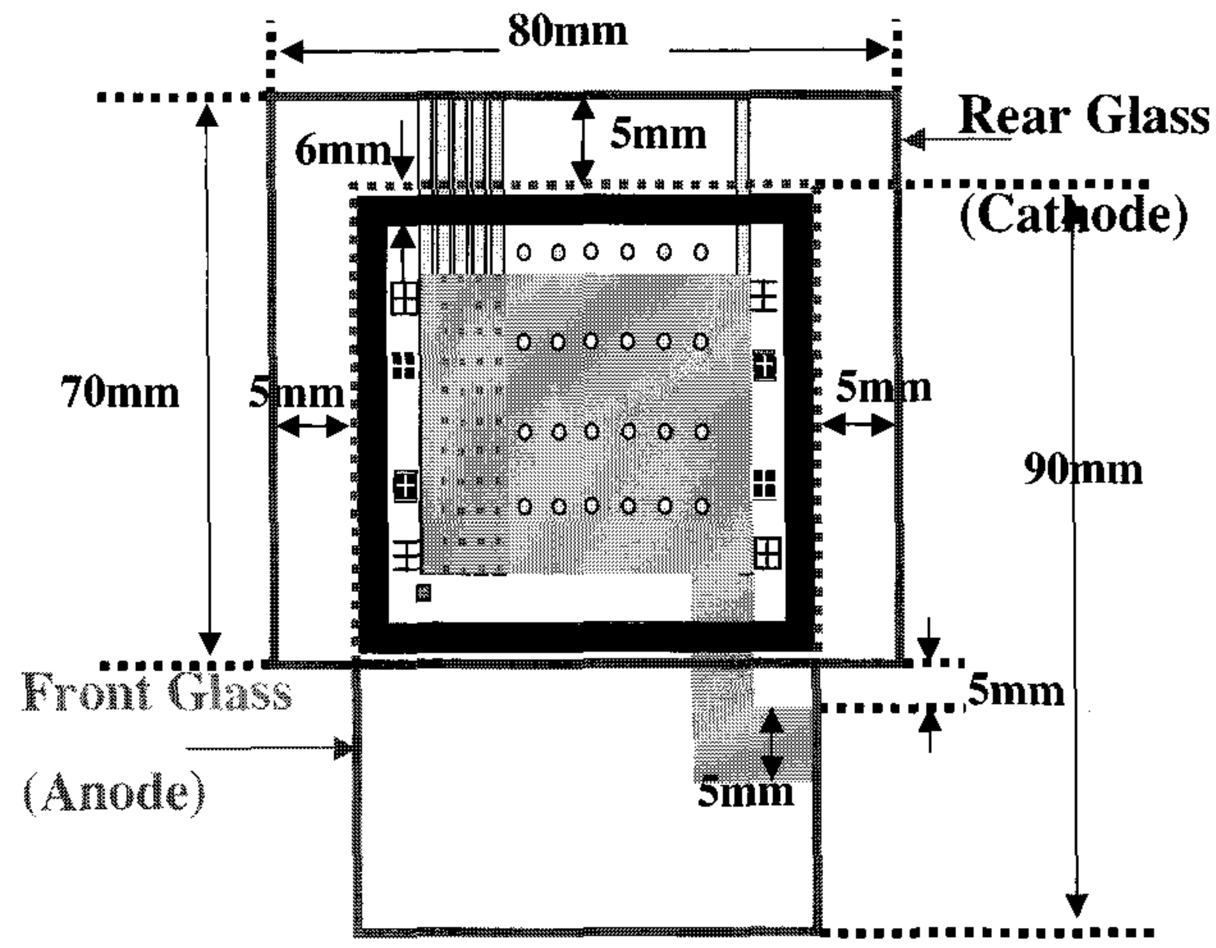


Fig. 1. Schematic diagram of a CNT-FED.

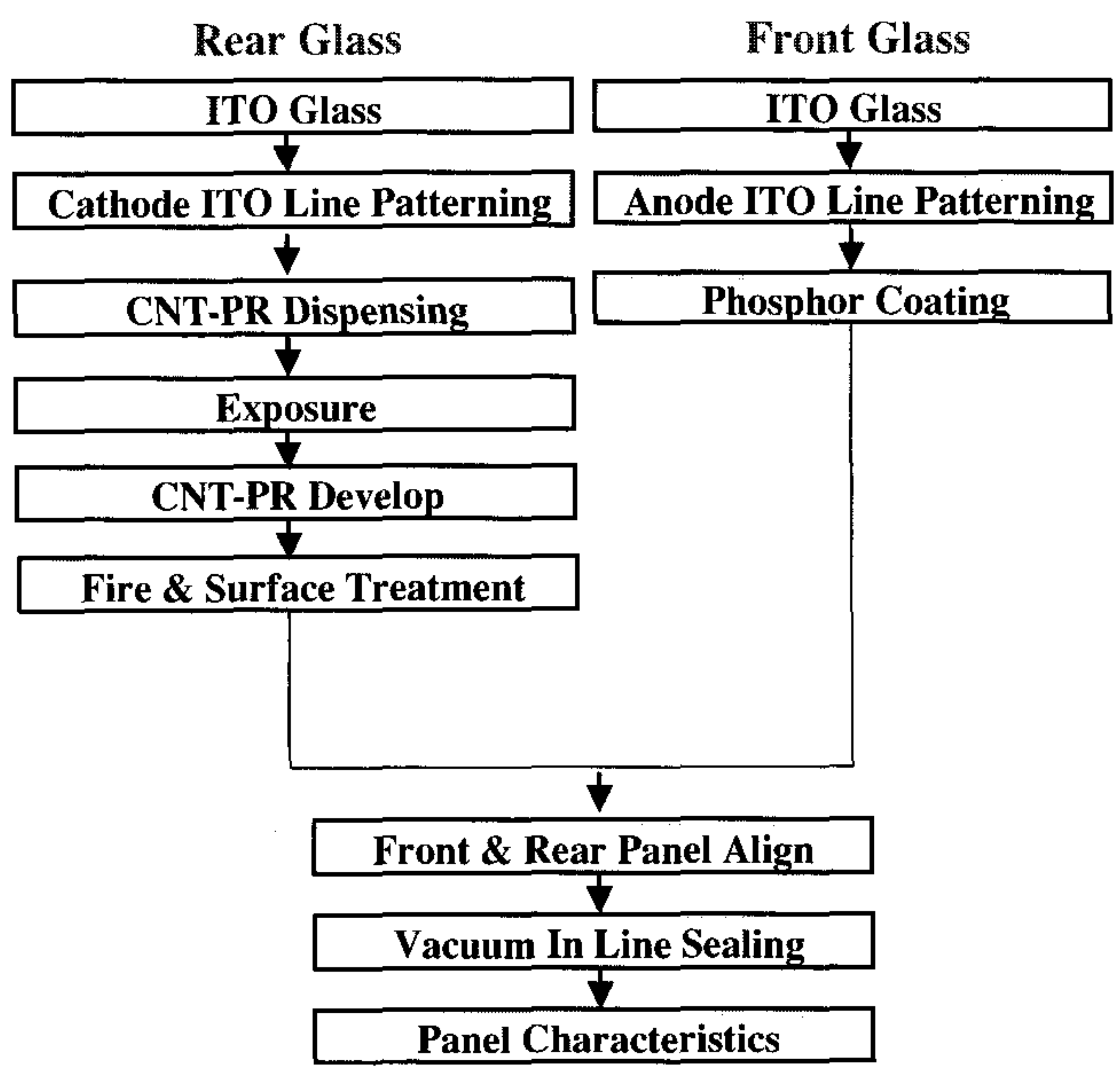
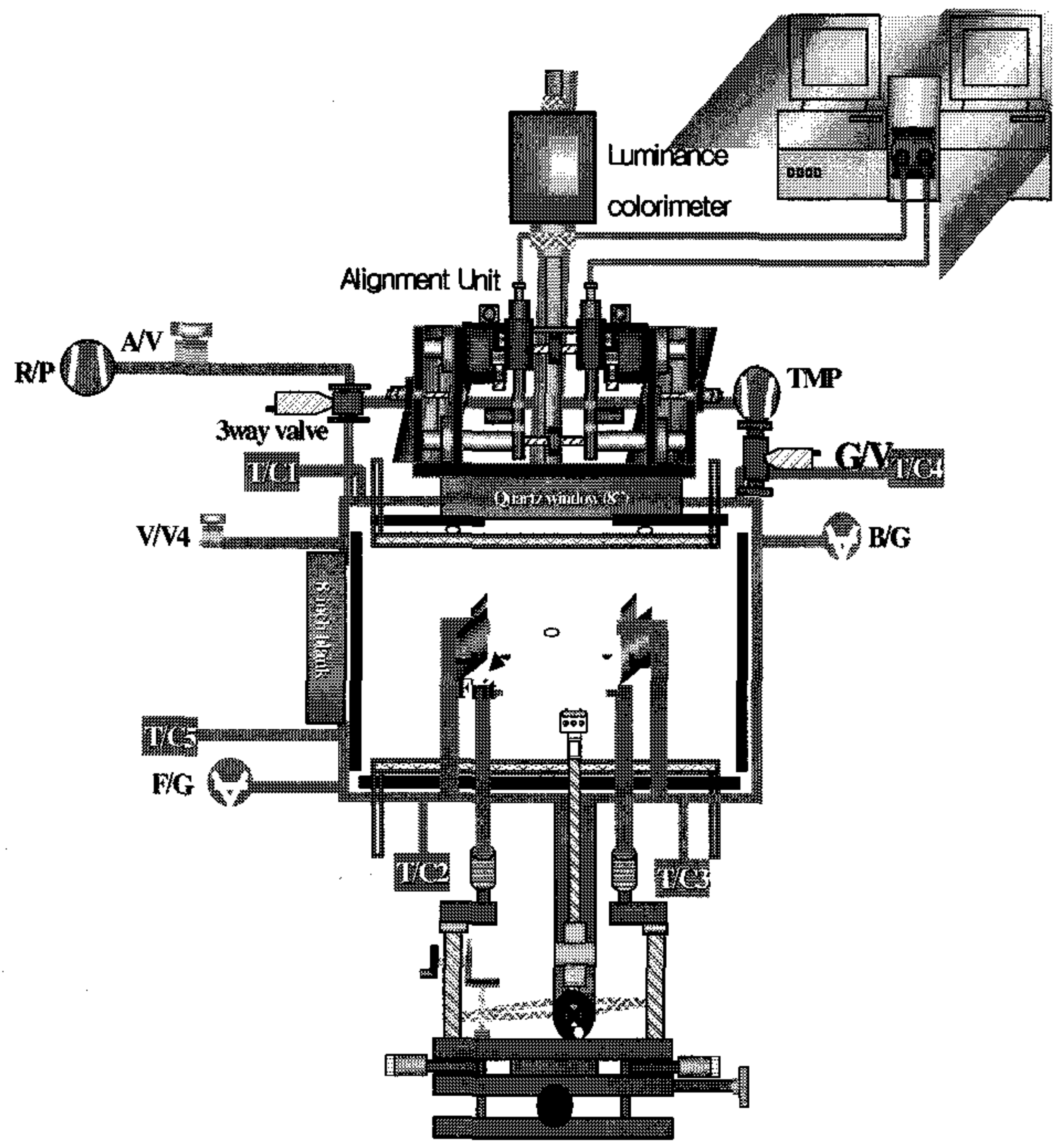
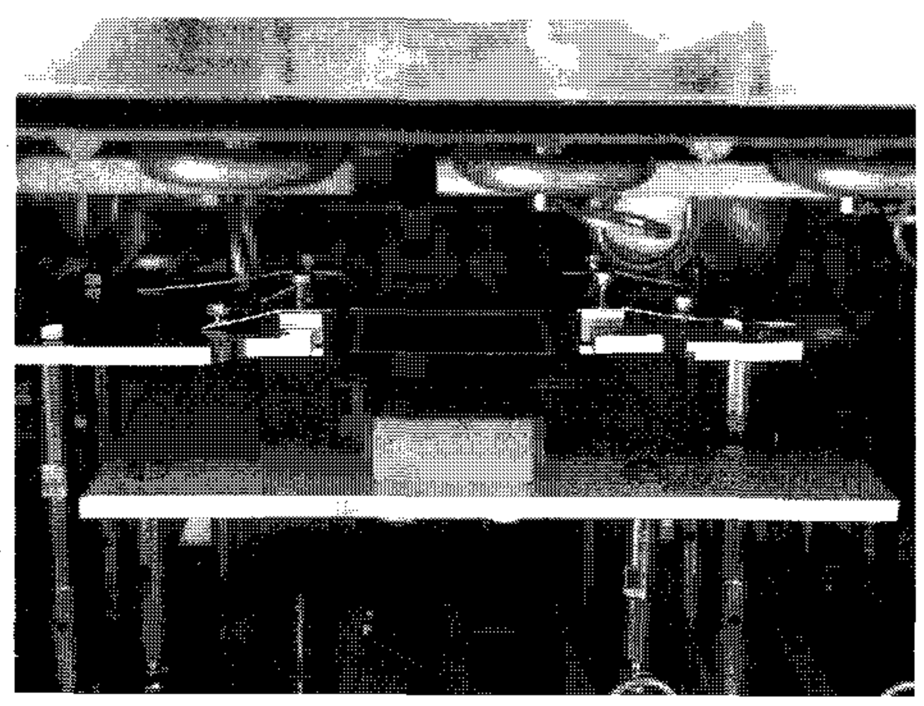


Fig. 2. Process sequences for the fabrication and sealing of the CNT-FED panel.

The CNT-emitters were formed on the cathode electrodes, the ITO lines of 340 μm width and 150 μm space. First, the photosensitive CNT-paste was printed on the front glass with the patterned ITO cathode lines. After soft baking the printed CNT-paste, it was exposed from the back-side of the CNT-printed face through a black metal mask which blocks the light passing through the space between cathode lines. After the exposed CNT-paste is developed, CNT-emitter lines only on the ITO lines remain.



(a)



(b)

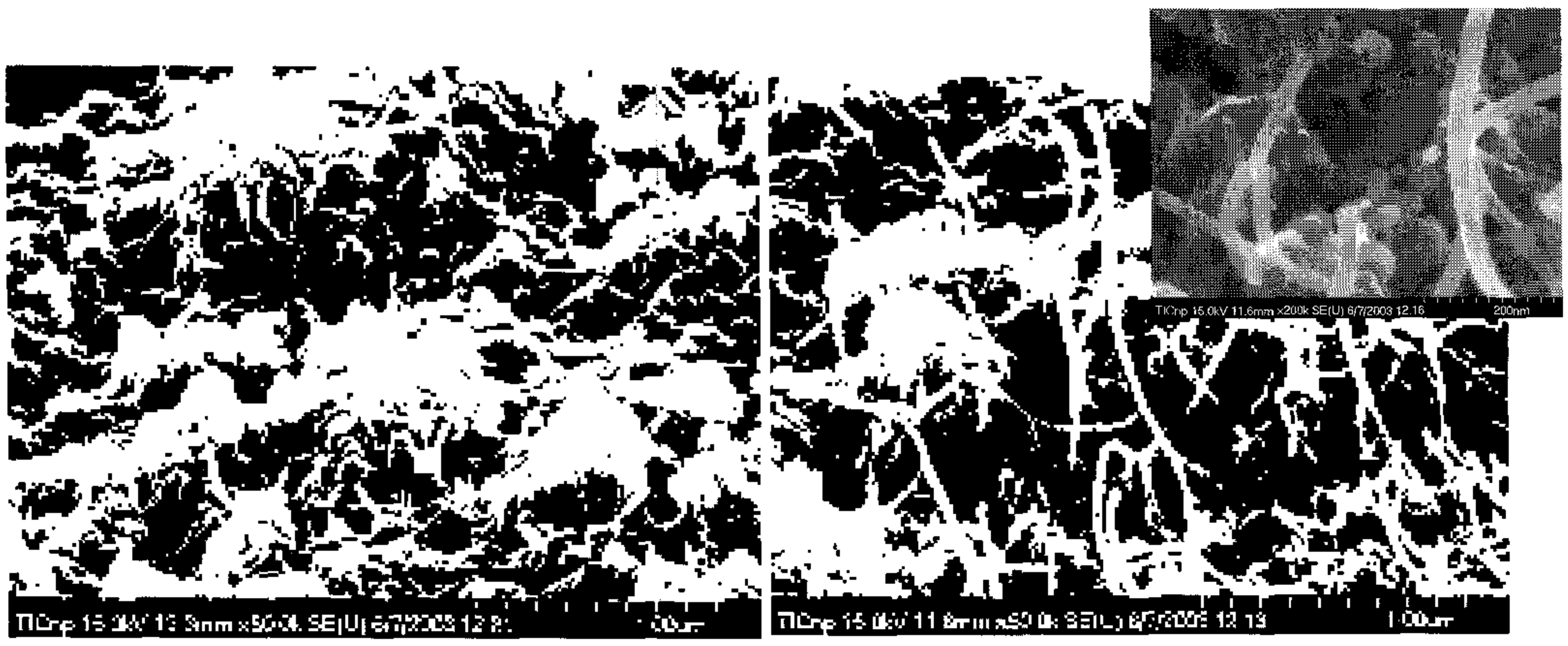
Fig. 3. (a) Schematic diagram of the equipment for vacuum in-line sealing technology and (b) picture during the sealing process.

Fig. 3(a) shows the system for the vacuum in-line sealing including the heating stages and in-line alignment system. The two glass plates were heated by using an infrared light source from a tubular heater. After arriving at the critical temperature, the two panels were put into contact by using positional controls. That is, the lower glass plate was moved up via a x-y-z-θ manipulator until it touched the upper glass plate. The manipulator gave a large pressure enough to seal the two plates. Fig. 3(b) shows pictures of during the sealing process of two plates loaded into the sealing chamber. The sealing area was set as 6 cm × 5.5 cm by frit dispensing. The panel was sealed when frit glass was fired and melted at the chamber temperature of 390 □. The chamber temperature was uniformly increased at a rate of 3 □/min. Clean frit surface was obtained without any cracks or pores. The gap between two glass plates was 0.2 mm which were sustained by glass spacers.

3. Results and Discussion

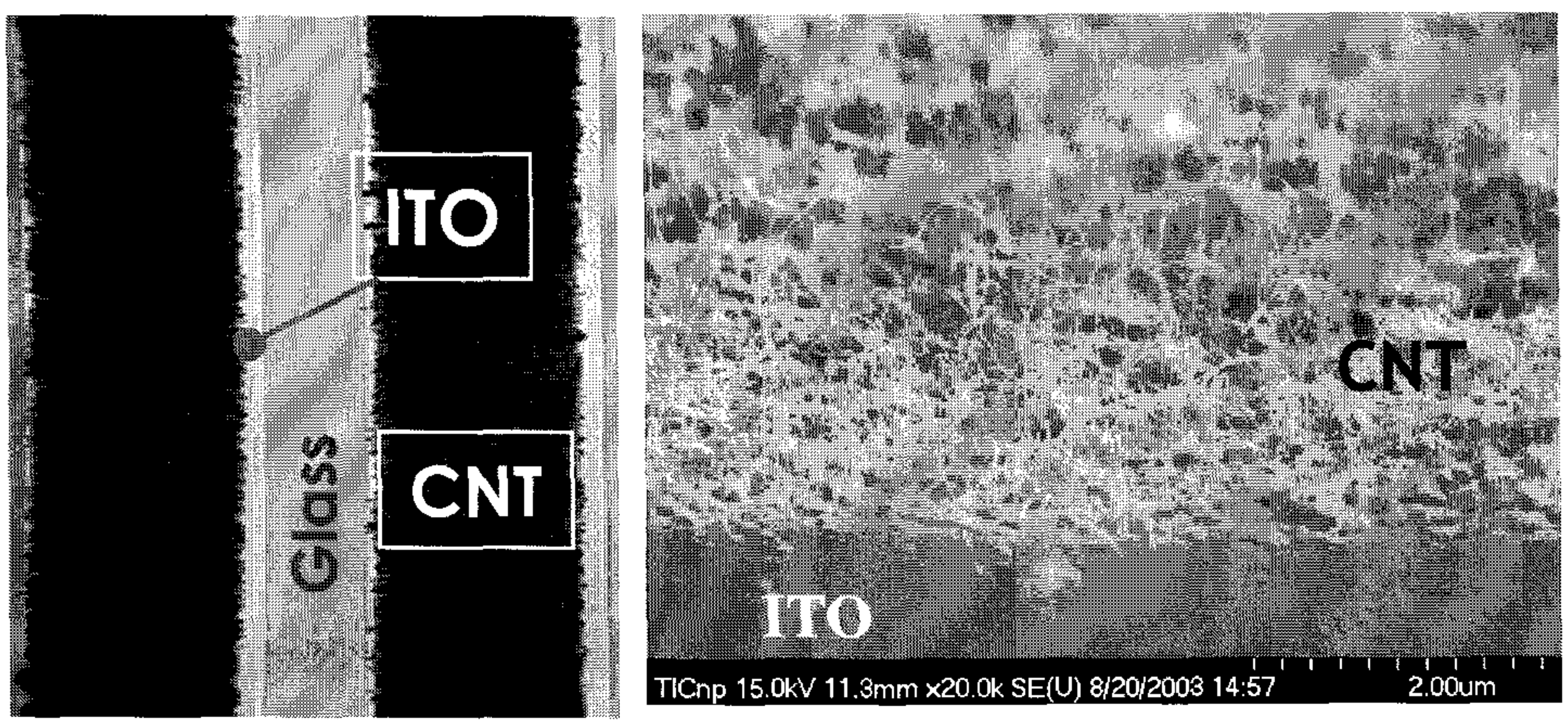
Figs. 4(a) and 4(b) show the scanning electron microscopy (SEM) images of screen printed CNT-paste before and after a surface treatment, respectively. The surface treatment was carried out by a taping method immediately after a hard baking of the screen-printed CNT paste. The diameter of CNT was about 20 nm after the surface treatment as shown in Fig. 4(b). The patterned CNT lines on the ITO cathode lines were shown in the optical microscopic view of Fig. 5(a). From the magnified SEM view of Fig. 5(b), it can be seen that the edge line of the stripe-type CNT-emitter was well defined on the ITO line.

For the vacuum in-line sealed panel, a leak test was performed and the result was compared with the reference pumping rate without the panel connection. From the measurement, we could not find any leak in the panel that was sealed by using the vacuum in-line sealing technology as shown in Fig. 6. Fig. 7(a) shows the temperature profiles of the panel and chamber during the sealing process. It is noted that the real panel temperature is indicated to be a little higher than that of the heater. This is attributed to the fact that the thermocouple for monitoring the panel temperature was directly contacted to the glass plate. In addition, the thermocouple for monitoring the heater temperature is a little apart from the metal tubular heater itself. Fig. 7(b) shows an operational CNT-FED panel fabricated by the vacuum in-line sealing technology. The vacuum level of the



(a) (b)

Fig. 4. SEM images of CNT-paste (a) without and (b) with the surface treatment.



(a) (b)

Fig. 5. (a) Optical microscopic view of the CNT-FED cathode lines with stripe patterns, and SEM view of a magnified line.

chamber was maintained at 1.4×10^{-5} torr at the sealing time.

Field emission properties of the sealed CNT-FED with a diode configuration were characterized and compared with those of the unsealed CNT-FED panel. For comparison, the unsealed CNT-FED plates were loaded into a electrical test chamber and measured with the same configuration as the sealed panel. The vacuum level of the test chamber was maintained at 6.8×10^{-5} torr, which is a little higher than that inside the sealed panel. Fig. 8 shows the current density-electric field obtained from the emission properties for the sealed panel and the unsealed panel, respectively. The inserted Fowler-Nordheim plot indicates that the anode current comes from field emission mechanism. From the results, we found that the sealed panel was had slightly better field

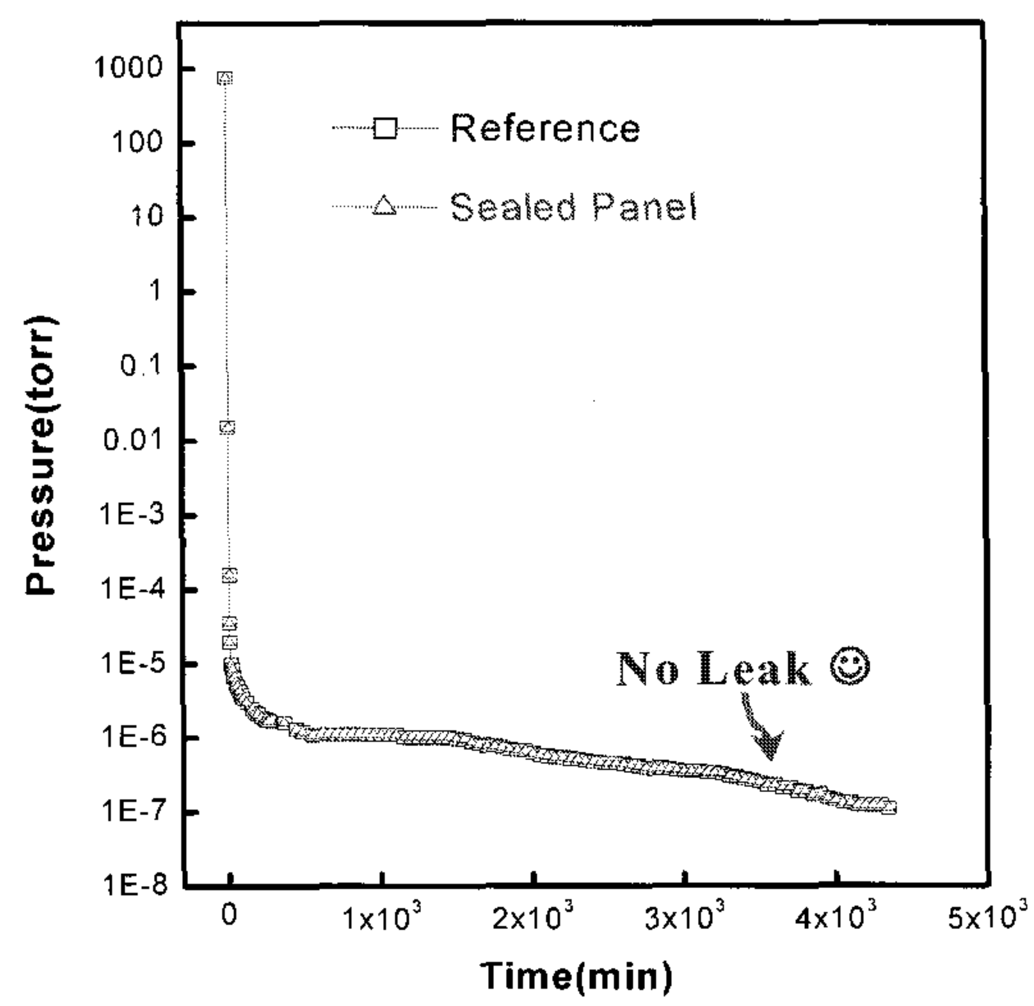
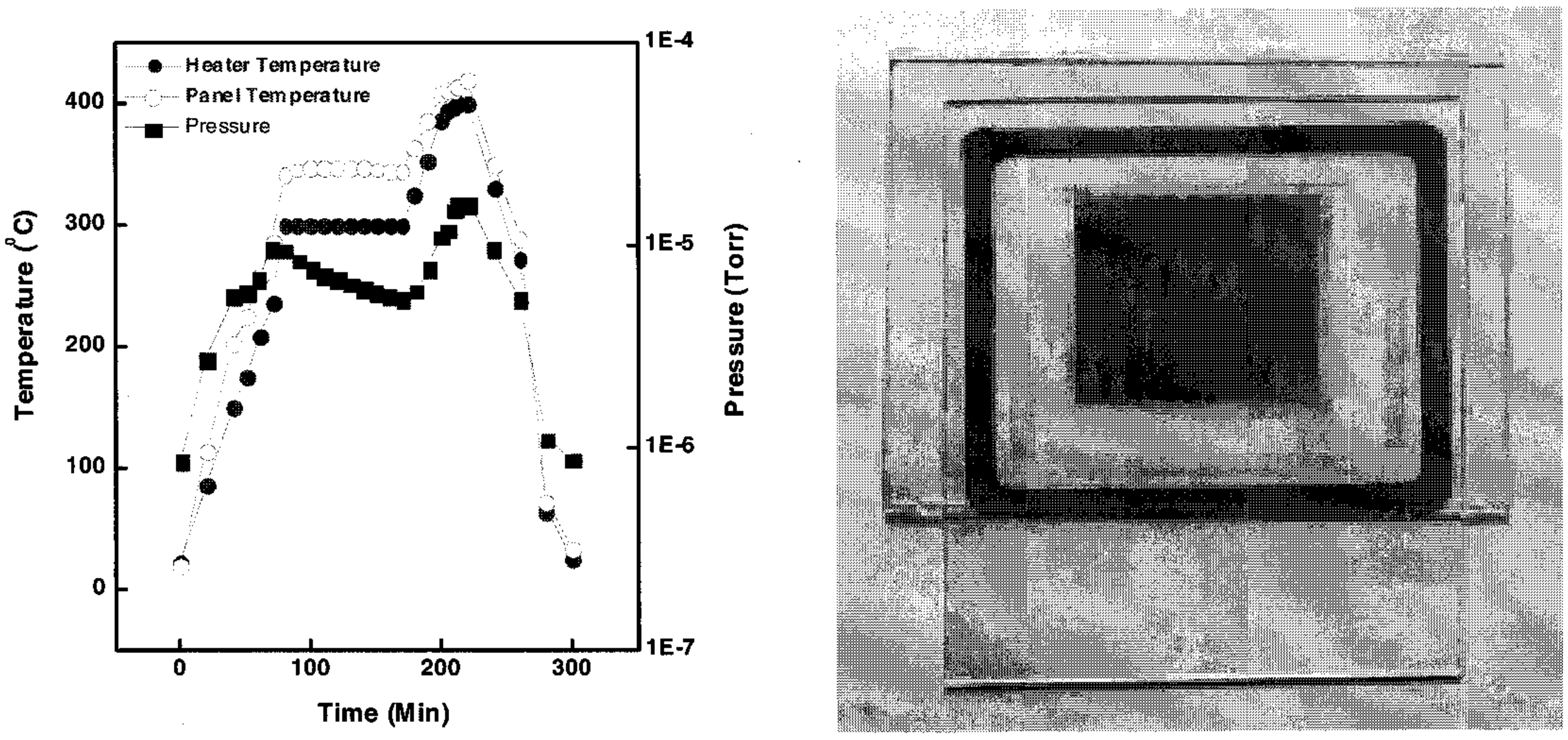
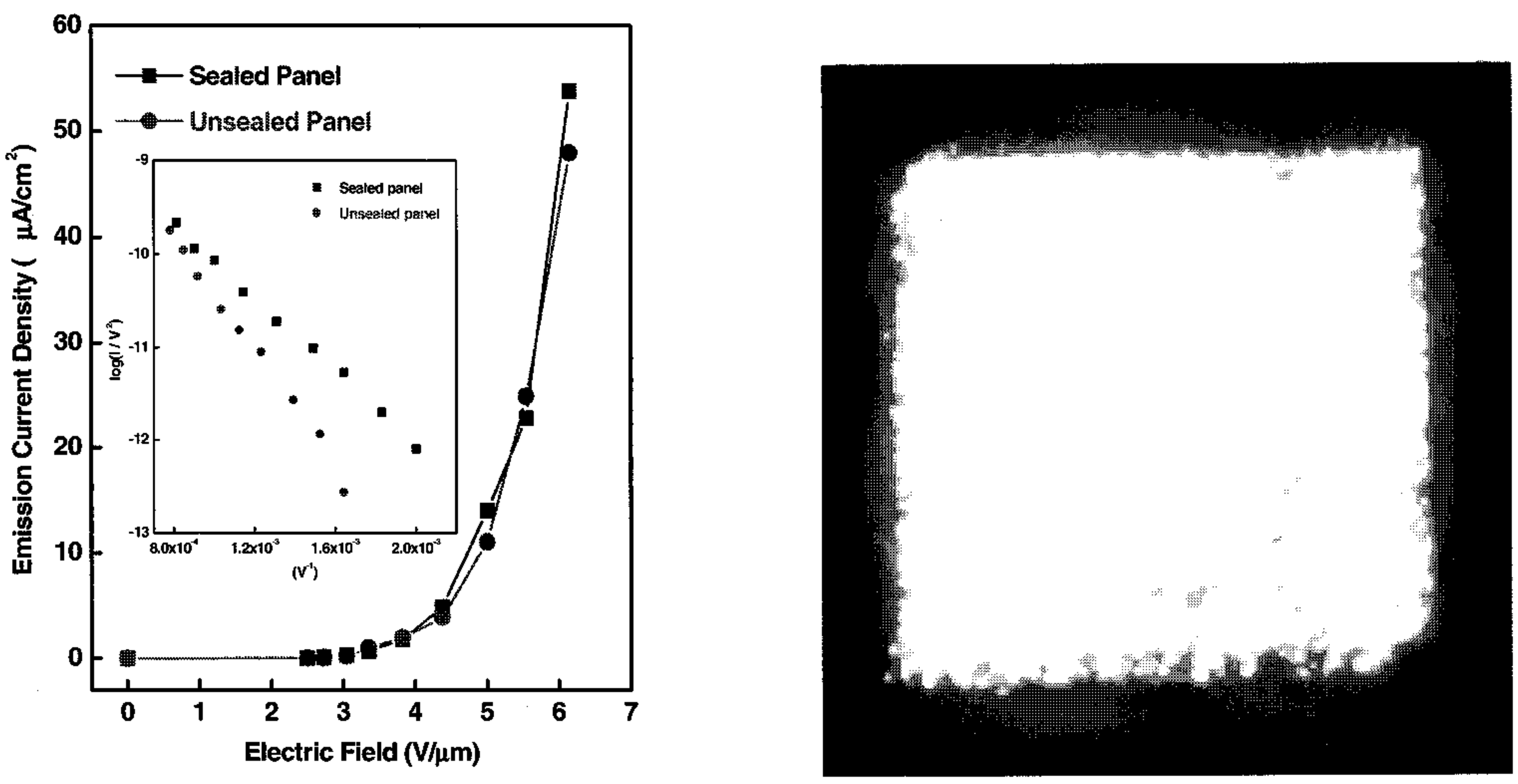


Fig. 6. Vacuum profile of the CNT-FED panel during a leak test for a pumping time of 72 hrs.



(a) (b)

Fig. 7. (a) Temperature profile including the vacuum level during the sealing process and (b) an operational CNT-FED with a 2 inch diagonal size panel fabricated by the vacuum in-line sealing technology.



(a) (b)

Fig. 8. Electrical characteristics of the sealed and unsealed panel : (a) current density-electric vs field characteristics, and (b) light emission pattern obtained at a current density of 243 $\mu A/cm^2$ by 2.0 kV(10 V/μm).

emission properties than that of the unsealed panel. It can be concluded that the real vacuum level inside the sealed CNT-FED corresponds well to 1.5×10^{-5} torr obtained from the vacuum gauge attached to the vacuum in-line sealing chamber and the CNT-FEA is not contaminated or affected by the sealing process.

Light emission began at an electric field of 3.5 V/μm, corresponding to the anode-cathode voltage of 700 V. As the applied voltage increased, the brightness increased prominently. At the applied voltage of 2.0kV(corresponding to 10 V/μm), almost the entire area of 2″ CNT-FEA was emitted uniformly as shown in the light emission pattern of Fig.7(b).

4. Conclusion

A 2-inch diagonal size diode type CNT-FED panel was fabricated by using a screen printing method and the vacuum in-line sealing technology. For the reliability of the vacuum level inside the CNT-FED panel which was sealed by the vacuum in-line technology, the field emission properties of fabricated panel were characterized and compared with those of unsealed panel which was located at similar vacuum level. The vacuum level of the sealed panel was expected to be maintained without any leak occurring inside the panel as the results of the field emission characteristics. From our results, we expect to obtain a better sealing process for more reliable and smarter CNT-FED than that fabricated by a conventional tube evacuation method. From the light emission pattern, the screen printed CNT can be used as a successful field emitter array via a photolithography process which operaties most efficiently at a voltage of less than 10 V/μm and provides an uniform and a high bright light emission.

References

[1] S. J. Kwon, K. S. Ryu, T. H. Cho, and J. D. Lee, J. Korean Phys. Soc. **33**, S440 (1998).
[2] J. A. Castellano, Solid State Technology 41, 67(1998).
[3] B. R. Chalamala, Y. Wei, and B. E. Gnade, IEEE Spectrum **35**, 42(1998).
[4] A. Roth, Vacuum technology(AMSTERDAM-NEW YORK-OXFORD, 52 VANDERBILT, NEW YORK N.Y, 1976), Chap. 7, p.329
[5] C. Boffito and E. Sartorio, Vacum Technik **35**, 212 (1986).
[6] 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**, 1227 (2000).