

Characterization of Triode-type CNT-FED Fabricated using Photo-sensitive CNT Paste

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Abstract

A carbon nanotube field emission display (CNT FED) panel with a 2 inch diagonal size was fabricated through screen printing of a prepared photo-sensitive CNT paste and vacuum in-line sealing technology. After surface treatment of the patterned CNT, only the carbon nanotube tips are uniformly exposed on the surface. The diameter of the exposed CNTs are usually about 20nm. The sealing temperature of the panel is around 390 °C and the vacuum level is obtained with 1.4×10^{-5}torr at the sealing. The field emission properties of the diode type CNT FED panel are characterized. Currently, we are in the process of developing a triode type CNT FED with a self-aligned gate-emitter structure.

Keywords : CNT paste, screen-printing, vacuum In-Line sealing

1. Introduction

Field emission display (FED) is generally described as a device with CRT-like image qualities and low power consumption and expected to be a good candidate for large-size flat panel display. Therefore, it is important to find the most cost-effective way to produce FED panels with large screen size.

To date, many investigations have been done on different types of emitters to achieve better emission characteristics and stability, such as Spindt-type emitter, surface conduction emitter ((SCE), metal insulator metal ((MIM), ballistic electron surface emitting device ((BSD), and carbon nanotube ((CNT) [1-5]. Among these, CNT has unique characteristics such as a high aspect ratio, a small radius, and a high electrical conductivity. By pasting the CNT and screen-printing the CNT paste, the CNT emitters are most promising for achieving low cost and large-size FED manu-facturing.

In this paper, we present the characteristics of the diode type CNT FED and will suggest the fabrication technology of a triode type CNT FED with a self-aligned gate-emitter structure. High vacuum sealing is one of the most difficult technologies in commercializing FED. We have applied a vacuum in-line sealing technology to a CNT FEA on soda-lime glass substrate with 2 inch diagonal size fabricated using a screen printing method on photo-sensitive CNT paste.

2. Experimental Procedures

2.1 Fabrication of the diode type CNT FED panel

In order to confirm whether the photo-sensitive CNT paste is a good emitter and the vacuum in-line sealing method is a successful packaging technology, first of all, we fabricated a diode-type CNT FED and characterized. First, the CNT FEA plate was fabricated by a screen printing method using CNT powder mixed paste. The CNT paste screen-printed over the patterned cathode (Cr) lines was exposed from the back-side of the glass plate through a black-matrix mask. The paste has a negative photo-sensitive feature, and thus the uv exposed CNT paste remained after the developing process, while the unexposed area was removed by a developer solution. After the development in a solvent, the remaining CNT emitters were

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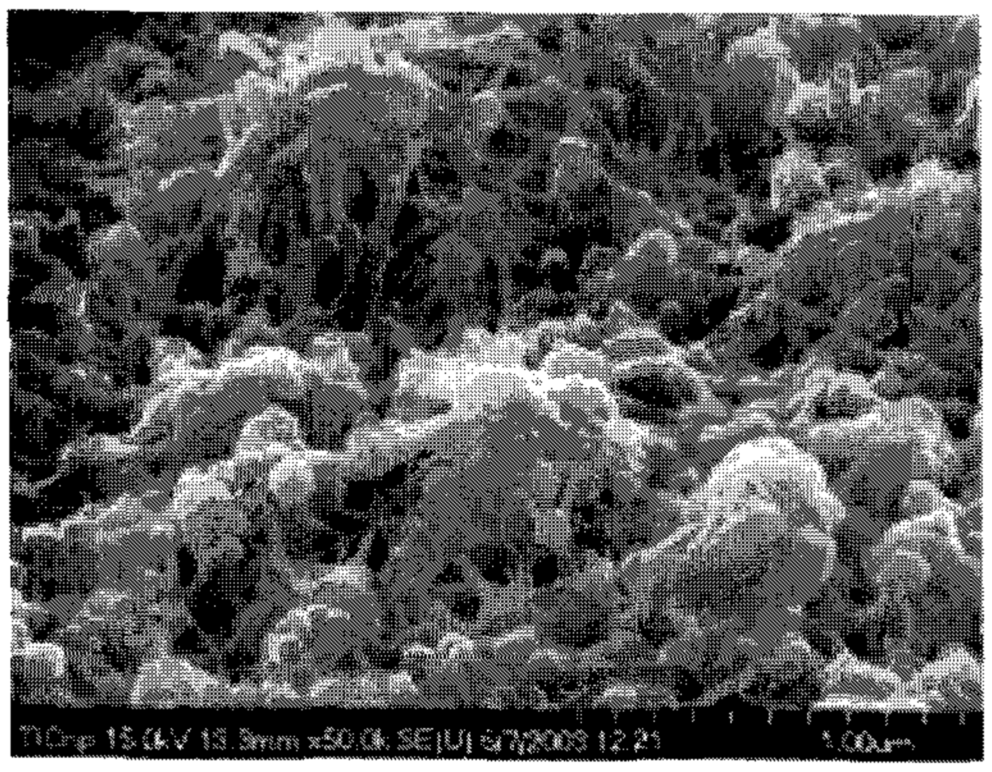

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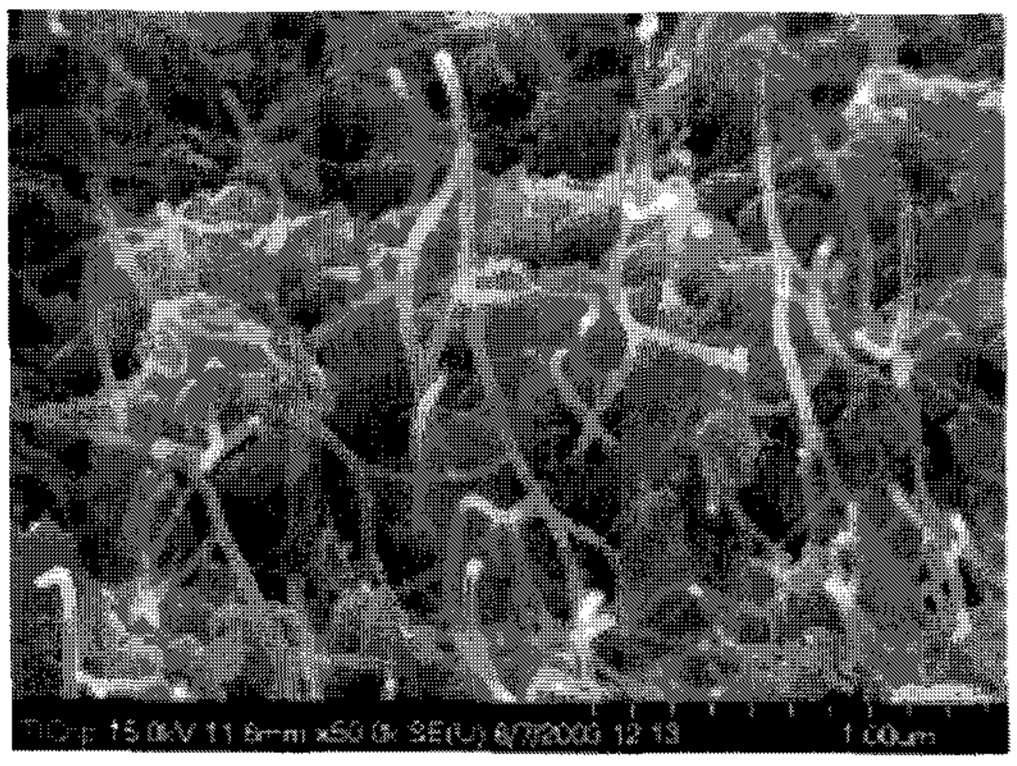


(b)

Fig. 1. Scanning electron micrographs of CNT paste (a) before surface treatment and (b) after surface treatment.

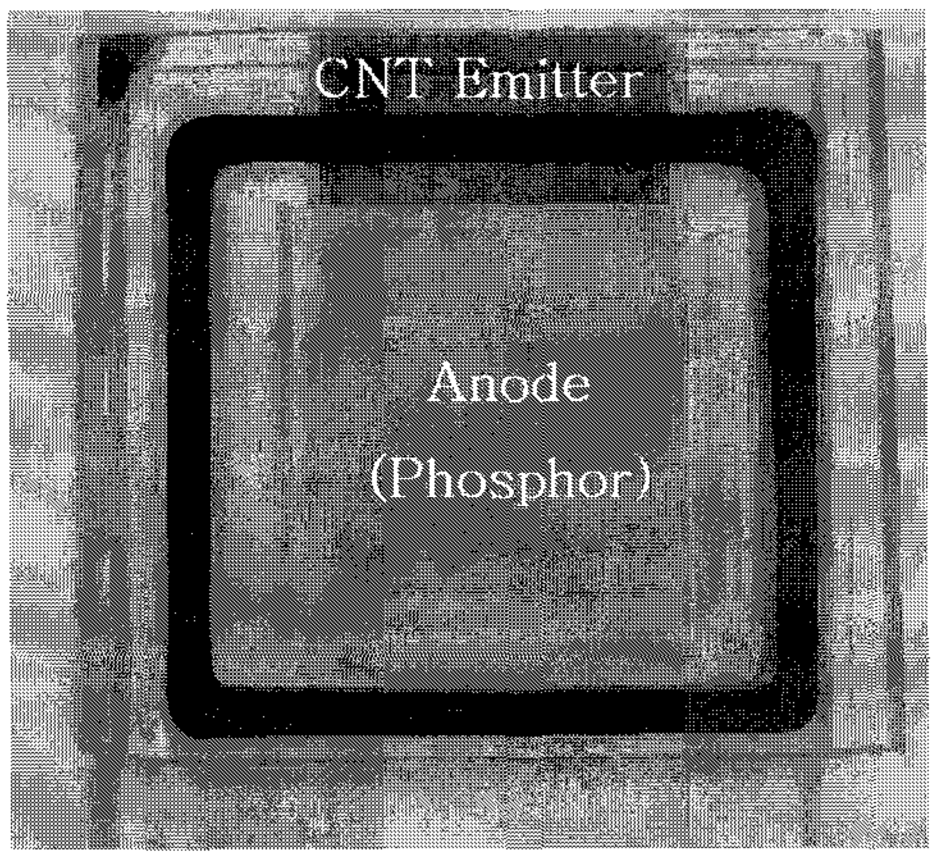


Fig. 2. An vacuum in-line sealed diode type CNT-FED.

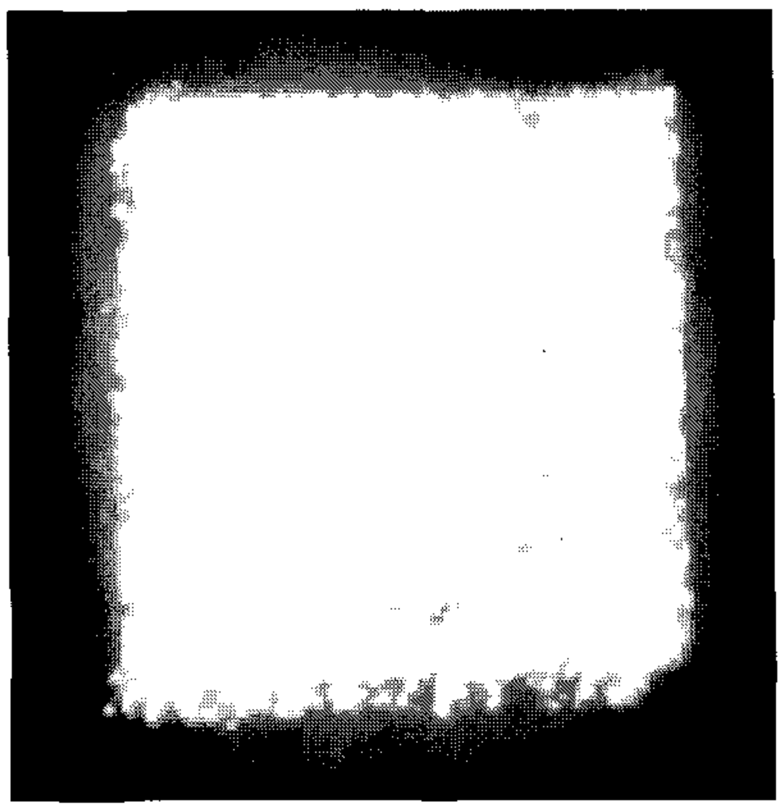


Fig. 3. Light emission pattern of the diode type CNT FED at the applied voltage, $V_{a\text{-}c}$ of 2.0kV.

baked at 450°C for 30min. The fired CNT film was surface-treated using an adhesive taping method. Fig. 1 shows the scanning electron microscope ((SEM) views of the untreated and the surface treated films. Through the surface treatment process, the binder components on the surface area of the paste were removed and only CNTs were exposed. Then, the anode plate was prepared with a patterned ITO electrode. Finally, two plates were sealed by using a dispensed frit glass paste inside a high vacuum chamber.

Next, to seal the CNT emitter and the phosphor screen glass plates, two plates were loaded into a vacuum sealing chamber. The heating of the two glass plates was done by using an infrared light source from a tubular heater. After the critical temperature was reached 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 enough press to seal the two plates. The sealing area was defined as 6 cm x 5.5 cm by frit dispensing. The panel was sealed when frit glass was fired and melted at a chamber temperature of 390 °C. The chamber temperature was uniformly increased at a rate of 3 °C/min. The vacuum level was sustained at about $1\text{-}2\times10^{-5}$ torr (at the sealing temperature of 390 °C. Clean frit surface was obtained without cracks or pores. The gap between two glass plates was 0.2 mm sustained by glass spacers.

2.2 Field emission characteristics of a diode type CNT FED

Fig. 2 shows an operational CNT FED panel fabricated by the screen-printing and vacuum in-line sealing technology including a phosphor screen anode plate. The phosphor screen was fabricated by a spin coating method using phosphor powder mixed with vehicles, and photolithography. Then, anode plate was fired. Finally, two

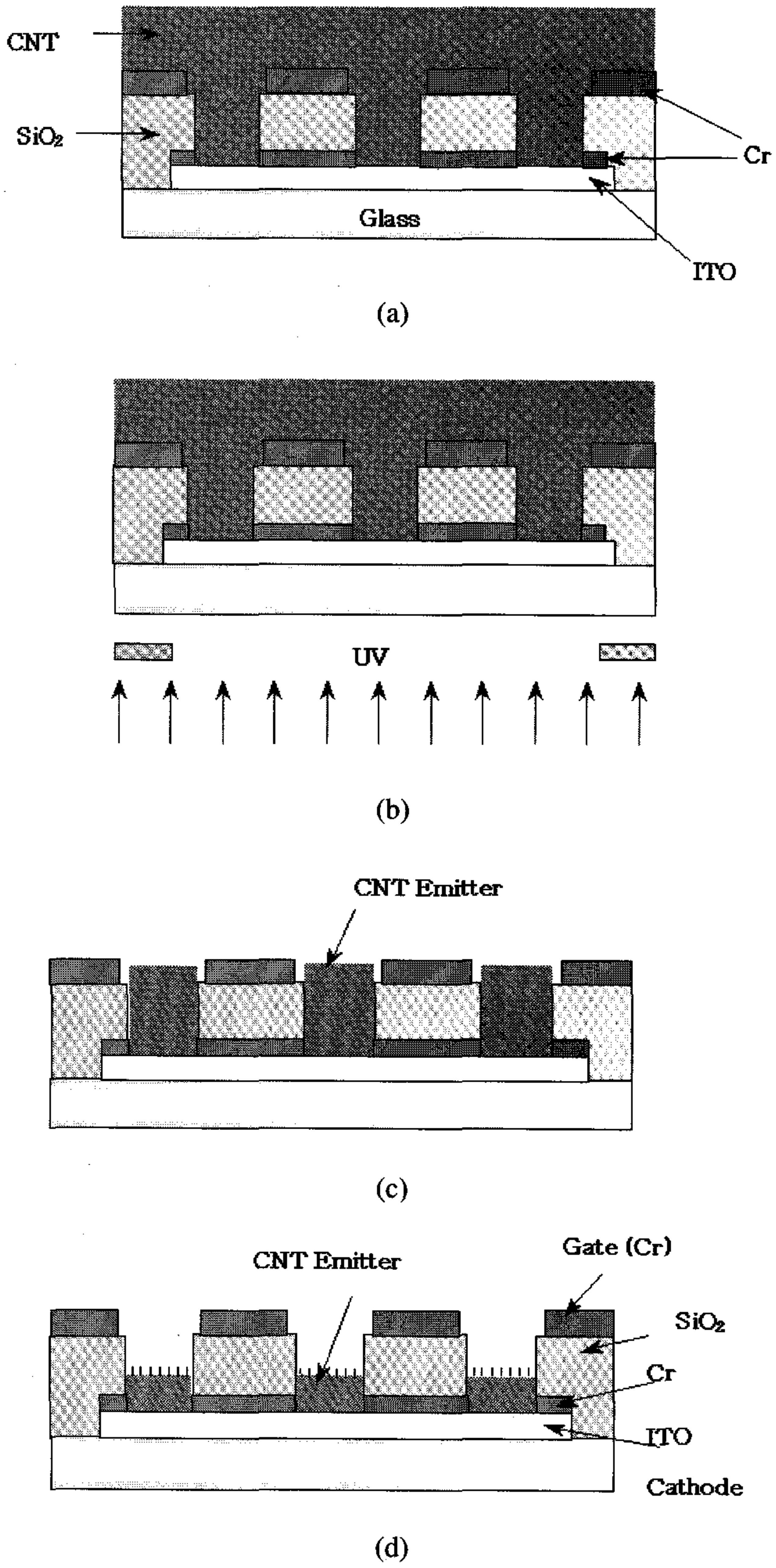


Fig. 4. Process flows of triode-type CNT-FED: (a) CNT paste screen-printing, (b) back-side exposure, (c) developing, and (d) firing & surface treatment.

plates were sealed inside a high vacuum chamber. The vacuum level was maintained at 1.9×10^{-5} torr at the sealing time.

Light emission was initiated 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 2.0 kV (corresponding to 10 V/μm), almost all area of 2" CNT FEA was emitted uniformly in the light emission patterns as shown in Fig. 3.

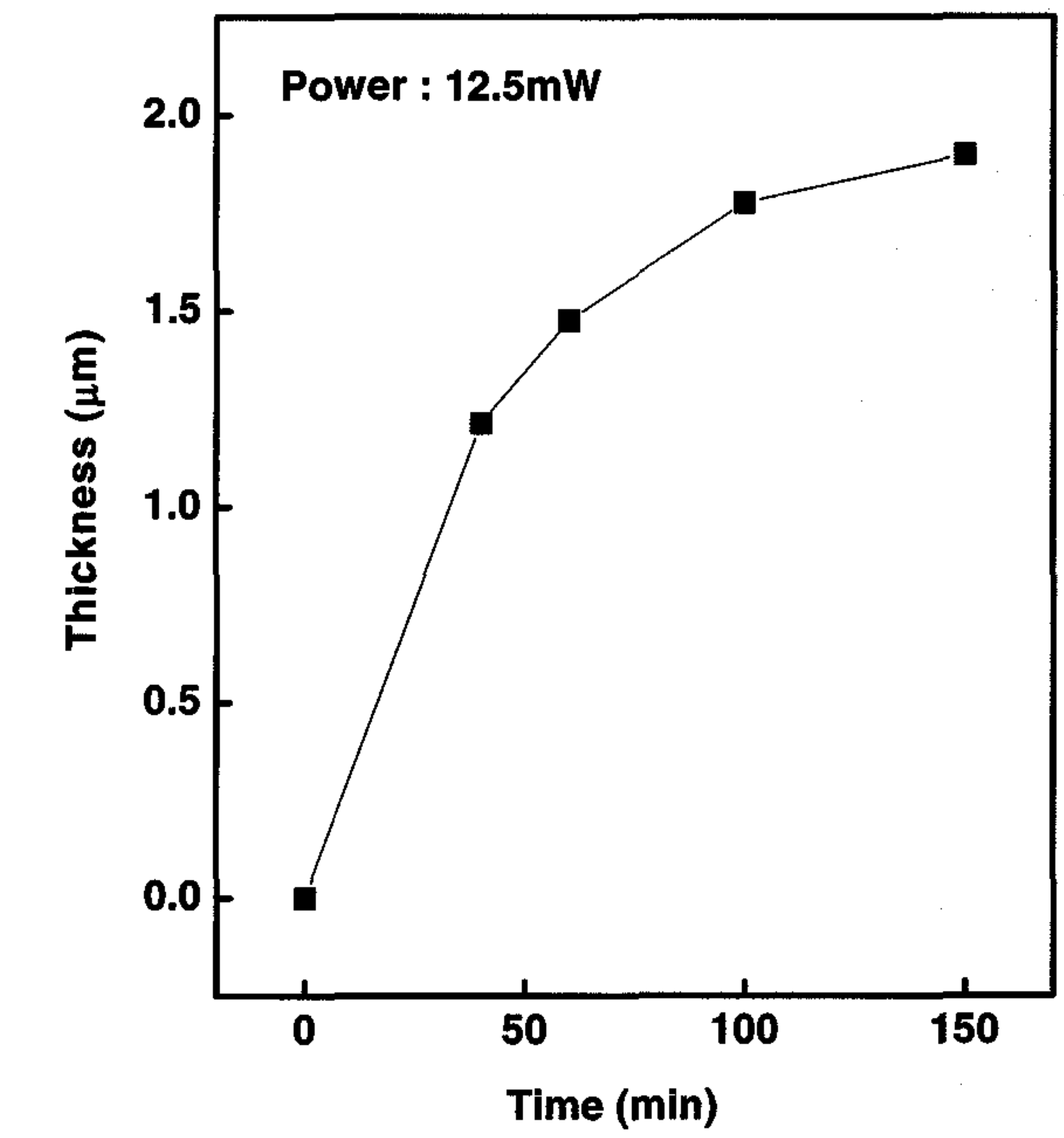


Fig. 5. Thickness variation of the CNT paste depending on the expose time right after development.

3. Fabrication of a Triode Type CNT FED

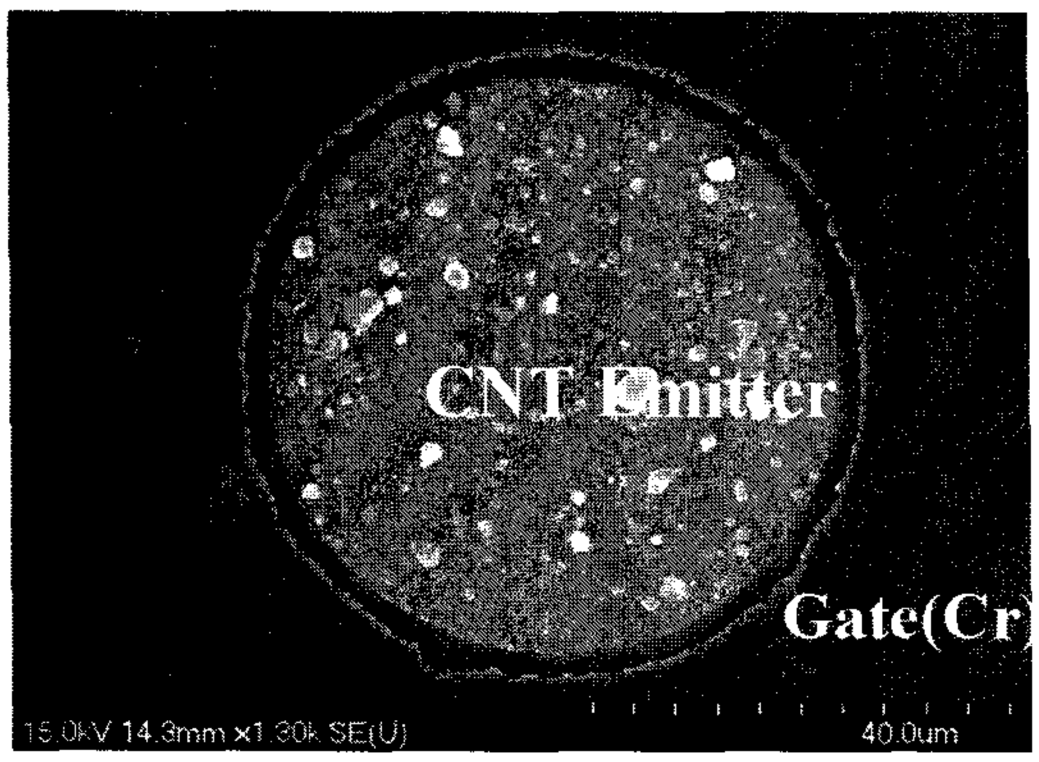
In order to reduce the turn-on voltage for the electron emission in order to avoid certain arcing problems, a triode type CNT FED with a gate electrode is generally preferred. We have set up the process sequences for the triode type CNT FEA as shown in Fig. 4. In this structure, the gate hole and the CNT emitter are self-aligned with each other. The cathode lines are composed of ITO layer covered with Cr metal layer. By using only one gate hole mask, the processes including gate hole etching, gate oxide etching, and cathode Cr etching can be sequentially carried out.

Then, a photo-sensitive CNT paste was screen printed at the top of the glass plate for filling into the pre-formed gate holes. By exposing the uv light through the back side and developing in the solvent, the unexposed CNT paste was removed. Consquently, only and the exposed CNT paste inside the gate hole remained. The diameter of the formed CNT FEA was 50 μm and the diameter of the gate metal hole could be controlled easily by the gate hole etching time. In this experiment, the gate hole diameter was 64 μm.

The height of the CNT FEA can be controlled by the uv exposing time. It should be noted that the circle of the gate hole and that of the CNT FEA are concentric to each other, which emulates 'self-aligned structure'. The thickness of the CNT paste remained after the development is shown in Fig. 5 depending on the exposing time at the power of 12.5 mW.

At the exposure time of 150 sec, the fabrication of the gated CNT FEA was completed. After the surface treatment using the same method as making the diode type, the gated CNT FEA was fabricated as shown in Fig. 6. As shown, the circles of the emitter and gate hole are concentric, and the CNT emitter edge is clearly separated from the gate edge by about 2.5 μm.

Field emission characteristics were performed for the triode structure CNT FEA. The cathode glass plate with CNT FEA and the ITO coated anode glass plate with phosphor screen were loaded into the vacuum chamber.



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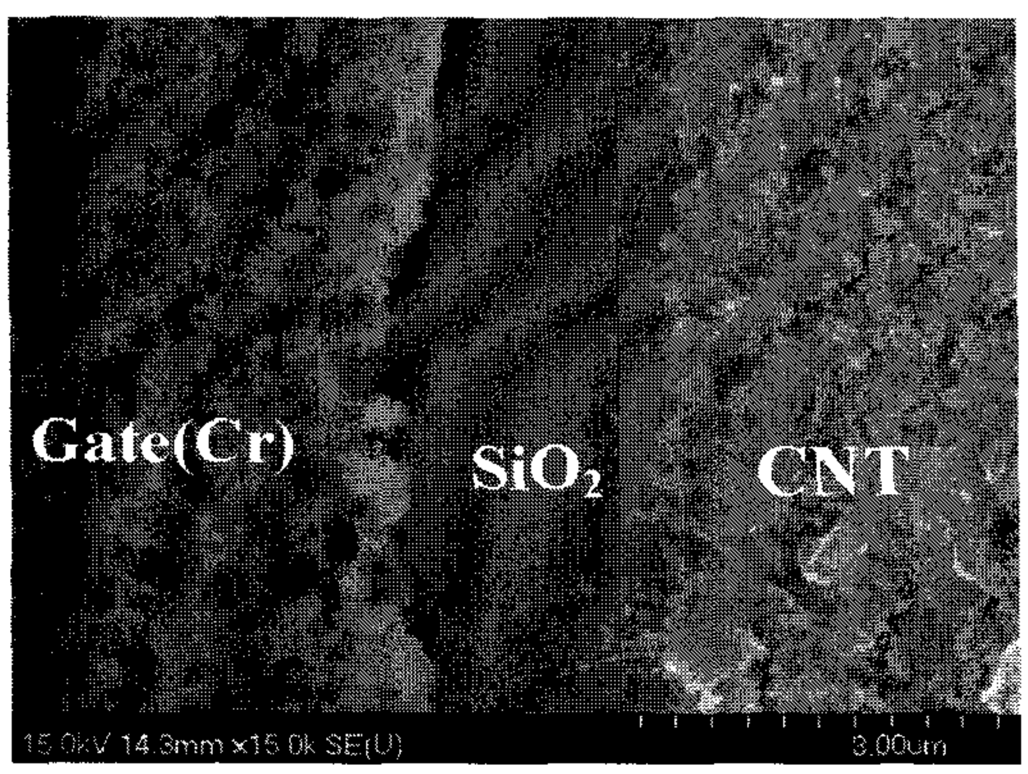
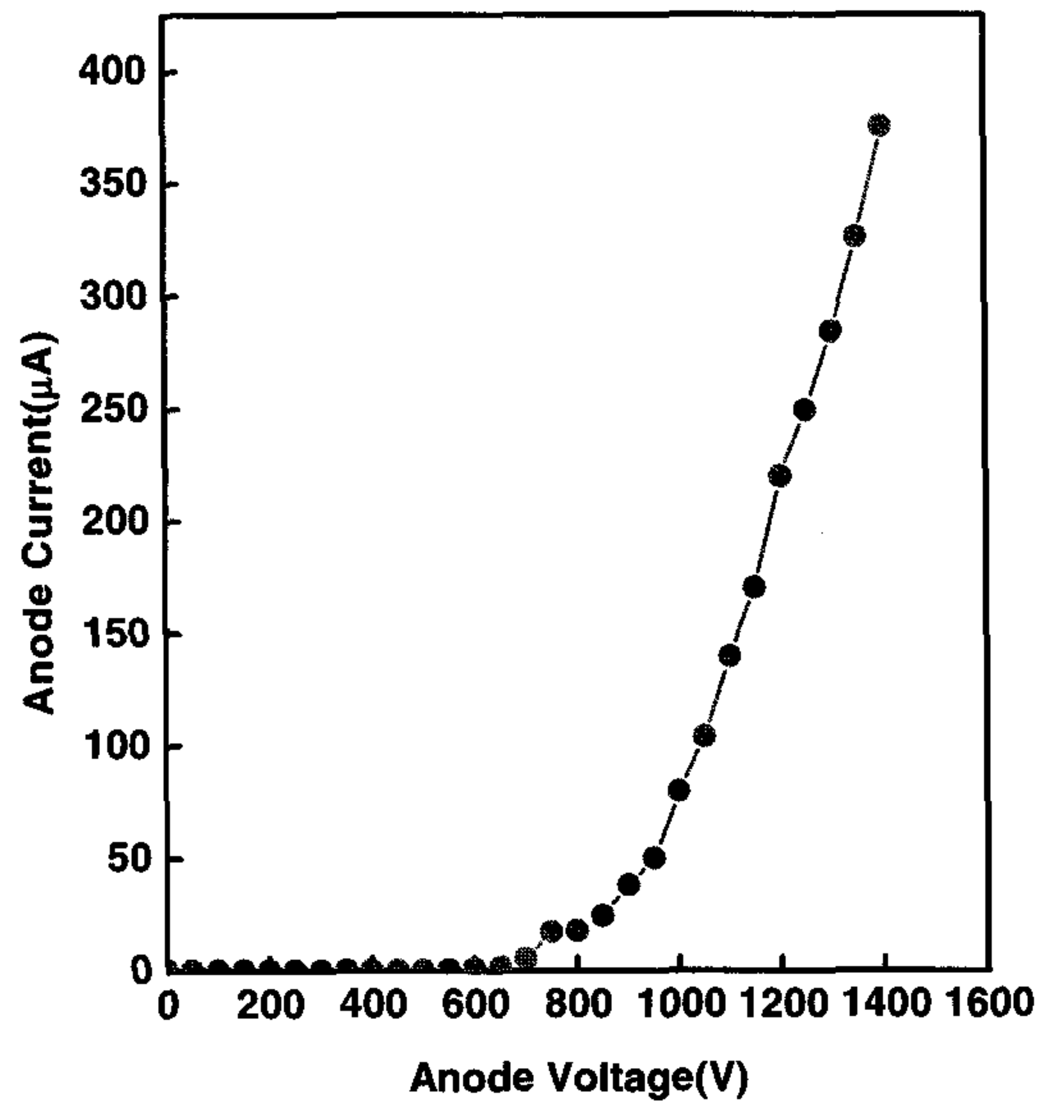


(b)

Fig. 6. SEM views of the gated CNT FEA : (a) an emitter hole, and (b) the edge of the holes.

The spacing between two glass plates was set by 200 μm and the final vacuum level obtained by turbo molecular pump was 1×10^{-6} torr. In order to obtain a proper anode bias, diode mode emission characteristics were measured by applying the anode voltage to the 2" diagonal full area through ITO electrode and floating the gate electrode. As shown in Fig. 7 (a), the emission was initiated at about 600 V which corresponds to a turn-on field of 3 V/μm. Therefore, in order to suppress the diode mode emission in



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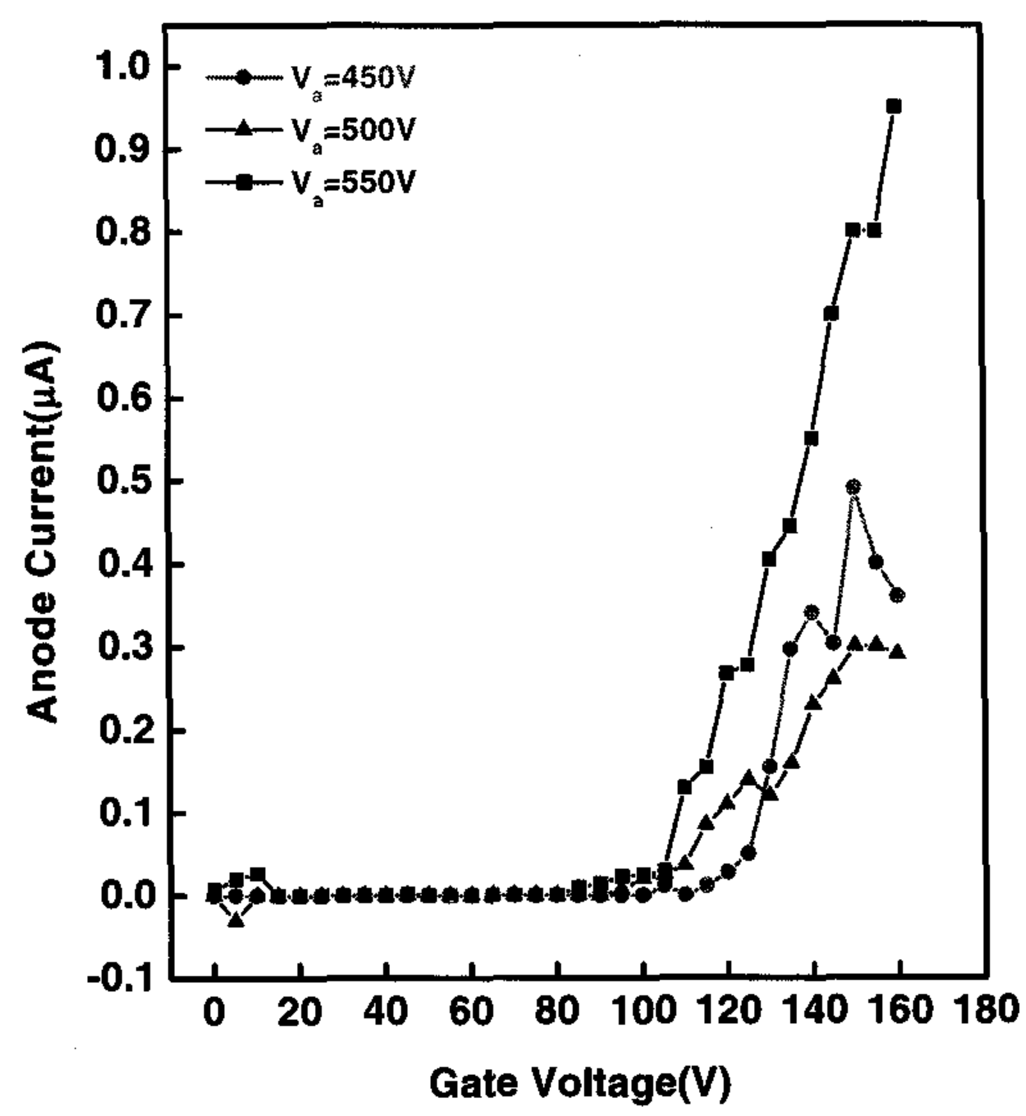
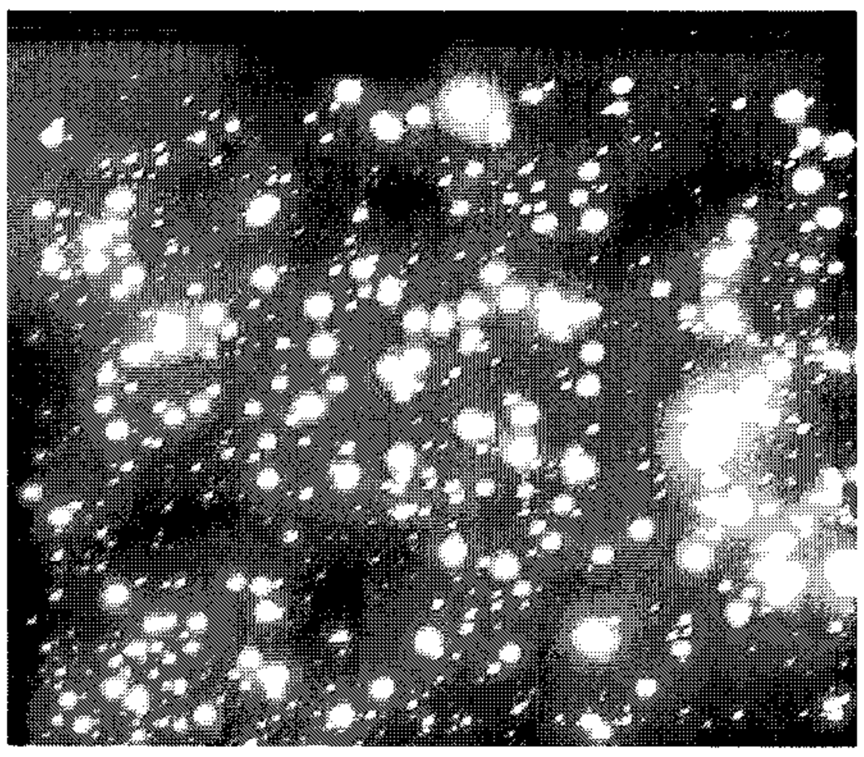


(b)

Fig. 7. I-V characteristics in (a) a diode mode emission with the gate voltage V_g floated, and (b) a triode mode emission depending on the anode voltage V_a.



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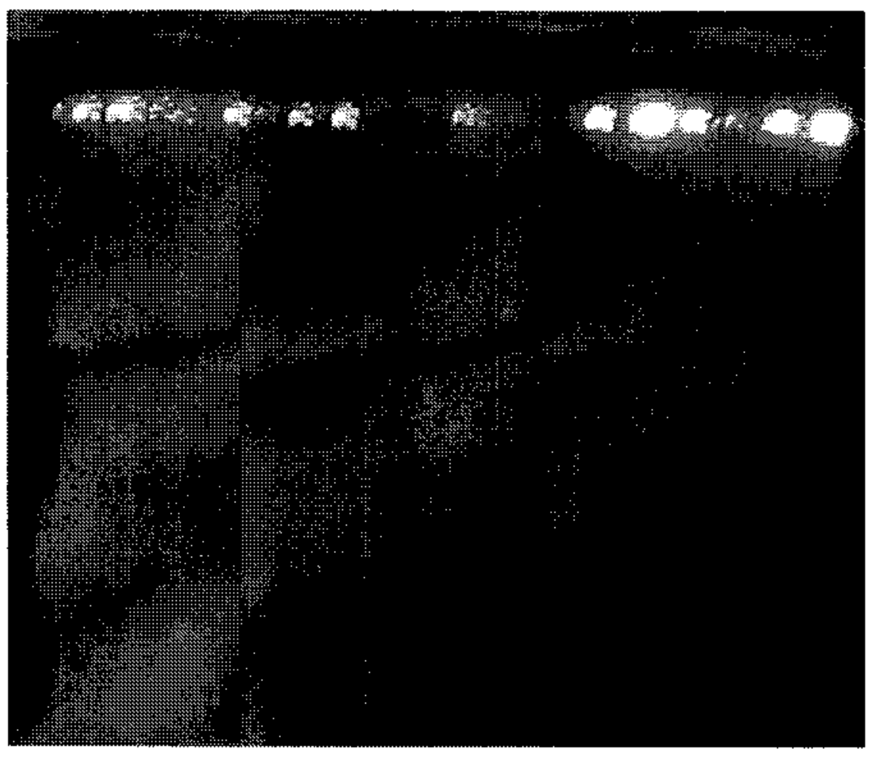

(b)

Fig. 8. Light emission characteristics in (a) the diode mode emission at V_a= 1kV with the gate voltage V_g floated (all anode area is biased by V_a), and (b) the triode mode emission at the gate voltage V_g = 160V and the anode voltage V_a= 550V (only top gate line is biased by V_g).

the triode mode operation, the anode bias voltage has to be set to approximately below 600 V for the spacing 200 μm. Secondly, triode mode emission characteristics were measured for the anode voltages of 450 V, 500 V, and 550 V. In this operation mode, the gate voltage was applied to only one line. As shown in Fig. 7 (b), the turn on voltage was around 100 V which corresponds to a turn on field of about 14 V/μm. However, as the anode voltage increased, the turn on voltage decreased a little and, as a while, the emission current level increased considerably. This phenomenon might come from accelerating the emitted electrons to the anode and resultantly, suppressing them to go to the gate electrode.

Figs. 8 (a) and ((b) show the light emission patterns for the diode mode emission and the triode mode emission, respectively. In the triode operation mode, the gate voltage was applied to only one gate line in order to confirm the suppression of a diode mode emission. We can see that the emission current is controlled effectively by the gate voltage at an anode voltage of 550 V .

4. Conclusion

Triode type CNT FED panel was fabricated by using a screen printing method of a photo-sensitive CNT paste. By using a back-side uv exposure through the concentric openings of a gate metal hole and a cathode metal window, a really self-aligned gated-CNT emitter could be obtained.

By creating of a self-aligned gate-emitter structure, it is expected that the screen printed photo-sensitive CNT paste is promising candidate for large-size field emission display.

References

[1] C. A. Spindt, P. R. Schwoebel, and C. E. Holland, *J. of Information Display*, **2**, 44 (2001).

[2] J. H. You, C. G. Lee, et al., *J. of Information Display*, **2**, 48 (2001).

[3] M. B. Lee and H. J. Lee, et al., *J. of Information Display*, **2**, 60 (2001).

[4] C. Boffito and E. Sartorio, *Vacum Technik*, **35**, 212 (1986).

[5] S. J. Kwon, K. S. Ryu, T. H. Cho, and J. D. Lee, *J. Korean Phys. Soc.*, **33**, S440 (1998).

[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).